Embodied Cognition: A Strength for Adolescents' Academic Achievement and Well-Being in the Classroom?

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Abstract
Background**:** Positive effects of embodied cognition and physical activity on executive functions, well-being and learning outcomes, have been found in toddlers and elementary school children. So far, embodied cognition in adolescents has not received much research attention. The aim of this study was to examine whether embodied cognition within a classroom context positively affects executive functioning, academic well-being and learning outcomes in adolescents.
Methods: A 5-week pilot study was performed in 4th grade secondary school with 16 students performing cognitive and motor exercises using a SenseBall© while learning and 26 other 4th graders attending class without the embodied cognition training. Pre- and post-tests were administered in both groups to determine students' executive functions and well-being. The intervention's impact was assessed on learning outcomes for Biology, French and Geography.
Results and conclusion: Embodied cognitive training showed positive but limited effects in terms of adolescents' working memory, satisfaction, social relationships, pedagogical climate and learning outcomes for French and Geography. Hence, this study may potentially contribute to insights within cognitive processes intertwined with learning processes in adolescents.

Keywords: Embodied Cognition, Executive Functioning, Academic Well-Being, Learning Outcomes, Adolescence

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Introduction

Physical Activity and Cognition

The connection between physical activity, well-being and cognition has already attracted many scientists' attention (Gomez-Pinilla & Hillman, 2013. Kempermann, 2008. Colcombe et al., 2004. Praag, 2008. Cotman et al., 2007). Physical activity may enhance well-being and has the capacity to reduce mental health related disorders (Gomez-Pinilla & Hillman, 2013). Furthermore, correlations between physical activity and cognitive abilities were first confirmed in experimental animal studies. Physical activity in rodents triggers a cascade of neurological changes in the hippocampus - a brain structure that plays a crucial role in memory processing – causing enhanced memory functioning (Gomez-Pinilla & Hillman, 2013). Physical activity in the early years of life affects learning capacity (Kempermann, 2008). Human studies show that being physical active increases task-related activity of cortical brain regions important for task completion (Colcombe et al., 2004). Physical activity increases neurogenesis and enhances the central nervous system's metabolism which plays a crucial role in maintaining the structural and functional plasticity of the brain, and is associated with learning and memory (Praag, 2008. Cotman, et al., 2007). Research in 4-to-18-year-old children find a correlation between physical activity and cognitive performance in language tests, math tests, memory and reading (Gomez-Pinilla & Hillman, 2013).

Embodied Cognition

Placing cognition in a sensorimotor context (consisting of sensory input, perceptual processing and muscle control) is called embodied cognition (Koziol et al., 2012). Briefly, embodied cognition is the interplay between body and brain, and within an educational context, it can be executed as a study method in which both senses and limbs are stimulated to improve cognitive abilities (Wilson, 2002). In conjunction herewith, physical activity has the potential to alter synaptic transmission in such a way that thinking, decision making, and behaviour are adjusted in brain structures involved in executive functions (Kopp, 2012). Executive functions are a subset of goal-oriented processes in our brain that allow someone to consciously direct their behaviour (Miyake et al., 2000). These functions are predominantly regulated in the prefrontal cortex. According to researchers, three core executive functions can be distinguished: (1) inhibitory control - the ability to control your own behaviour, emotions but also attention, (2) working memory - the temporarily retention of relevant information and its mental processing, and (3) cognitive flexibility – the ability to flexibly adapt to new demands, rules or priorities that arise with changing perspectives (Diamond, 2013). It is clear that cognitive processes are related to physical activity, yielding an inseparable interaction between the brain, the body, and the world (Mcclelland et al., 2014. Foglia & Wilson, 2013. Price et al., 2009. Wilson, 2002).

Educational research in toddlers show a significant improvement of recalling course content after a six-week embodied cognition intervention during science classes (Mavilidi et al., 2017). Another study by Mavilidi et al. (2018) show that toddlers who implement embodied cognition perform better in terms of executive functions (Mavilidi et al., 2018). As a result of physical activity, cerebral blood flow and oxygen supply to specific brain regions (responsible for learning and memory) rises (Hillman, et al., 2008). Research by Toumpaniari et al. (2015) show increased enthusiasm when a new foreign language is learned through embodied cognition (e.g., gestures or task-related physical activities) in comparison to toddlers who did not learn through embodied cognition. This positive attitude can induce better performances in learning activities (Toumpaniari et al., 2015). A study from McClelland et al. (2014) found that physical activity in a classroom context - i.e. embodied cognition - with primary school children leads to an improvement in learning outcomes for the courses English and math after a 12-week-intervention (Mcclelland et al., 2014). Other researchers argue that physical activity with seven-year-old children can result in about a 25% significant increase in learning outcomes of math after nine months while the control group only shows a significant increase of 17% (Have et al., 2018). Mullender-Wijnsma et al. (2019) performed a two-year embodied cognition intervention study in eight-year-old children and found better learning results in math and language courses (Mullender-Wijnsma et al., 2019).

However, only a few studies have been executed on embodied cognition in secondary education. One study demonstrates that students who combine cognitive (learning) tasks with the use of a bicycle desk have increased motivation and enhanced mental resilience compared to students who did not execute this type of embodied cognition (Pilcher & Baker, 2016). Similar results are found in high school students that studied the cranial nerves (e.g., the hypoglossal nerve) through embodied cognition (mimicking cranial nerves, e.g. sticking out the tongue because of the nerve functions in the tongue muscles) (Dickson & Stephens, 2015). Hence, more in-depth research is necessary to investigate whether this motivation could have a significant effect on overall well-being.

Purpose of the Present Study

Previous research has shown a strong relationship between embodied cognition and the improvement of executive functions, academic motivation and learning results, especially in preschool and primary school children (Mavilidi et al., 2017. Mavilidi et al., 2018. Toumpaniari et al., 2015. Mcclelland et al., 2014. Have et al., 2018. Mullender-Wijnsma et al., 2019). Studies on the effects in adolescents are less well covered in academic research. Hence, the aim of the current pilot study was to examine whether embodied cognition positively affects executive functioning, learning outcomes and overall well-being in adolescents through the implementation of an embodied cognitive training (ECT). Current study can provide us with more insight into cognitive processes intertwined with embodied learning in secondary school adolescents.

Methods

Participants

Participants were students from a public secondary school in Maaseik in the Flemish part of Belgium. The intervention group consisted of 16 students (of whom eight boys) in their 4^{th}-year (study area language and sciences, aged 15 till 17 years, M = 15.56 years, SD = 0.63). The control group consisted of 26 students (of whom 11 boys), also in their 4^{th}-year (study area economics and human sciences, aged 15 till 17 years, M = 15.33 years, SD = 0.48). Selection of the students took place through the age of the pupils (adolescence = target group), and the willingness of teachers (and corresponding courses) to participate. Dutch was the first language of all students and they had normal (or corrected to normal) vision and hearing. None of the students had an officially diagnosed developmental disorder or psychiatric disorder. Since all participants were still minors, both students and parents signed an informed consent, guaranteeing anonymity and safety during the whole intervention period. Students were also informed that they could stop their participation at any time for any reason. This study was approved by the Medical Ethics Committee of Hasselt University (Belgium).

For the executive functioning and academic well-being tests, only 13 and 15 students were included for the control and intervention groups respectively due to Covid-19 quarantine. For learning outcomes, 26 and 16 students were included in the control and intervention groups respectively. Group characteristics are given in table 1.

	Executive Functions and Academic Well-being Tests		**Learning Outcomes**	
	Control Group (n = 13)	**Intervention Group (n = 15)**	**Control Group (n = 26)**	**Intervention Group (n = 16)**
Sex: Number of Boys (%)	4 (30.77)	11 (73.33)	8 (30.77)	11 (68.75)
Mean Age (Years)±SD	15.08±0.29	15.47±0.52	15.33±0.48	15.56±0.63
Mean BMI (kg/m^2)±SD	21.31±2.40	21.10±2.79	21.46±2.31	21.94±2.99
Mean Received Training Number±SD	0	8±0.74	0	8±0.73

Note. SD = standard deviation, n = number of students.

Table 1: Student's Characteristics.

Procedure

Students had a practice session with a SenseBall© before the start of the intervention. The intervention period lasted for five weeks in which students performed five long (50 minutes) and four short (10 minutes) ECT sessions based on the participated teachers and accompanying courses. During these sessions, course content for French, Biology, and Geography was rehearsed rhythmically by using the SenseBall©. The exercises consisted of eight series that were designed by a youth football coach that is experienced in ECT, and the difficulty level was gradually increased with each exercise. Additionally, a Dutch training video was made available online for the teachers and the students in which all the physical exercises with the SenseBall© were clearly demonstrated (Everaert, 2021). The control group did not participate in ECT but followed the regular curriculum.

All students – regardless of their participation in the intervention or control group – administered pre-intervention (pre-I) and post-intervention (post-I) tests using a computer, assessing their executive functioning and well-being at school. The assessment of executive functions comprised of five validated tests: a Stop-Signal Test (response inhibition and impulse control), an Attention Network Test (abbreviated ANT, alertness and attention) and a series of Attention Span Tests (AST) including a Reading Span Test, an Operation Span Test and a Mixed Span Test (all three examining working memory). Details are given in appendix A. Academic well-being was assessed by a validated questionnaire, developed and used by the Flemish Ministry of Education (Vlaamse overheid, 2013). Academic well-being was defined in terms of satisfaction (school- and class environment), engagement (focus and concentration during the courses), social relationships among students, pedagogical climate (student's vision on the teacher) and academic self-concept (student's vision on their learning outcomes). The questionnaire was completed individually through a Google Form.

The learning results for the courses French, Biology, and Geography were measured by calculating the mean grades before and after the intervention. A visualization of the intervention period is given in figure 1.

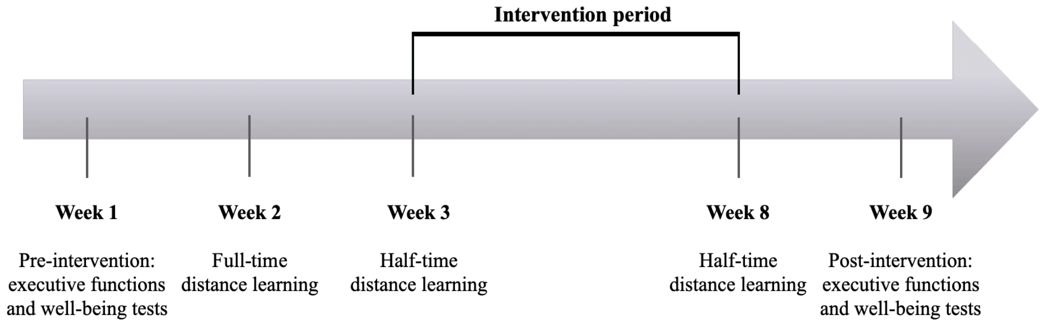

Figure 1: Visualization of the intervention period.

In summary, the following participants' data was collected: name, age, sex, body weight, length, body mass index (BMI), executive function test outcomes, well-being test outcomes, and learning outcomes for French, Biology and Geography.

Statistical Analysis

Statistical analysis was executed using R (RStudio v1.2.1335). A significance threshold was set at *P*-value <0.05. Data of the executive function tests, well-being test, and learning results were log-transformed to meet the criterium of normality.

A two-sided paired t-test – also called the within-groups hypothesis in this study - was done to check whether there was a difference within the pre- and post-executive function tests (mean reaction times), pre- and post-well-being at school and pre- and post-learning outcomes for French, Biology and Geography in the intervention group or in the control group. Besides, an unpaired t-test – called the between-groups hypothesis in this study - was executed to check whether there was a difference between the intervention group and the control group for the executive function tests (mean reaction times), well-being at school and learning outcomes for French, Biology and Geography. Effect sizes were expressed as Cohen's d.

To control for possible effects of covariates between two or more groups, and to increase statistical power because of low sample size, the same associations were checked via an ANCOVA-model analysis with the integration of independent variables (executive functions: mean RT pre-I; well-being: mean well-being score pre-I; learning results: mean learning results pre-I). Besides, the ANCOVA-model included following covariates: sex, BMI, number of received trainings, and groups (received the intervention [intervention group] or not [control group]). These covariates were added together to the ANCOVA-model. Assumptions were met (normality, equal variance, independent observations, and linearity between the independent variables with the mean RT, the mean well-being score and the mean scores of the learning results after the intervention) except for homogeneity. Effect sizes were calculated using generalized eta squared.

Results

As mentioned in the methods section, unpaired and paired t-tests were performed to check whether embodied cognitive training ensured better executive function test results, higher academic well-being and higher learning outcomes. Few results have emerged from these t-tests. Additionally, it was opted to perform the ANCOVA model analysis to control for possible side effects and to increase statistical power. Overall, more significant results have emerged from this analysis with bigger effect sizes.

Embodied Cognitive Training and Executive Functions

No difference was found between executive function Reaction Times (RT) of the intervention group and the control group post-I (Table 2). Hence, we checked for possible main effects and interaction effects within the intervention or control group by building an ANCOVA-model (Table 3). The standard model included 'mean RT pre-I' to examine the effect of this variable on mean RT post-I. The standard model also included following covariates: BMI, sex, number of received trainings, and group (intervention versus control group). The standard model failed to show significant effects (Table 3).

	Pre-I			**Post-I**			**Pre- and post-I**	
	I M ± SD	C M ± SD	I–C *P* (*d*)	I M ± SD	C M ± SD	I–C *P* (*d*)	I pre – I post *P* (*d*)	C pre – C post *P* (*d*)
Stop Signal Test	242.40 ±482.47	249.42 ±420.92	1.00 (-0.01)	239.80 ±450.13	244.08 ±450.08	0.82 (-0.01)	0.79 (0.00)	1.00 (0.01)
Attention Network Test	580.13 ±126.96	622.33 ±129.36	0.17 (-0.23)	572.60 ±124.03	621.17 ±155.02	0.06 (-0.24)	0.68 (0.04)	0.96 (0.01)
Reading Span Test	18154.66 ± 9748.09	16479.21 ± 8411.43	0.28 (0.13)	16456.51 ± 7043.46	15407.17 ±6649.71	0.37 (0.11)	0.06 (0.14)	0.28 (0.10)
Operational Span Test	8926.14 ±2947.33	12486.18 ±10300.90	**< 0.01** (-0.33)	9201.20 ±3737.29	9372.89 ±3059.13	0.89 (-0.04)	0.61 (-0.06)	**< 0.01** (0.29)
Mixed Span Test	9106.07 ±3359.64	9740.80 ±3930.28	0.44 (-0.12)	9820.98 ±4749.87	8799.27 ±3074.15	0.16 (0.18)	0.23 (-0.12)	**0.03** (0.19)

Note. Pre-I = pre-intervention, Post-I = post-intervention, I = Intervention group, C = Control group, M = mean RT in milli seconds, SD = standard deviation, P = significant when <0.05, d = Cohen's d effect size: small effect size 0.20; medium effect size 0.50; large effect size 0.80.

Table 2: Average Reaction Times (RT) for Pre- and Post-Test Executive Functions.

However, sex was included in the final model since sex can be relationally related to executive functions (Grissom & Reyes, 2019). ECT can be a strength in terms of having a medium effect on working memory in the intervention group within the Reading Span Test ($P < 0.01$, $\eta^2G = 0.49$) since the intervention group took less time (1698,152 ms) to perform this test (Table 3). However, this positive effect of ECT could not be observed for the Operational Span Test nor the Mixed Span Test. The adolescents within the intervention group took more time (275,054 ms) to perform the Operational Span Test ($P < 0.01$, $\eta^2G = 0.45$) and the Mixed Span Test (714.914 ms, $P < 0.01$, $\eta^2G = 0.42$) (Table 3).

Standard model: Independent variable: mean RT pre-I, tested covariates: all			
	P	***F***	**η²G**
Mean RT pre-I	0.07	3.94	0.21
Sex	0.16	2.22	0.13
BMI	0.39	0.78	0.05
Training	0.06	4.25	0.22
Group	0.06	4.20	0.22
Sex*BMI	0.87	0.03	< 0.01
Sex*training	0.66	0.20	0.01
Sex*group	0.74	0.11	< 0.01
BMI*training	0.88	0.03	< 0.01
BMI*group	0.95	< 0.01	< 0.01
Training*group ; Sex*BMI*training ; Sex*training*group ; Sex*BMI*group ; BMI*training*group ; Sex*BMI*training*group	NA	NA	NA

Final model: Independent variable: mean RT pre-I, covariate: sex					
Effect between	***P***	***F***	**Mean RT Pre-I ± SD**	**Mean RT Post-I ± SD**	**η²G**
Reading Span Test pre- and post-I	**<0.01**	14.61	18154.66 ±9748.09	16456.51 ±7043.46	0.49
Operational Span Test pre- and post-I	**<0.01**	13.23	8926.14 ±2947.33	9201.20 ±3737.29	0.45
Mixed Span Test pre- and post-I	**<0.01**	10.16	9106.07 ±3359.64	9820.98 ±4749.87	0.42

Note. Pre-I = pre-intervention, Post-I = post-intervention, RT = Reaction Time, ms = milliseconds, P = significant when <0.05, F = variance ratio, η^2G = generalized eta squared effect size based on Pearson's r: small effect size 0.10; medium effect size 0.30; large effect size 0.50.

Table 3: Significant Outcome Measures of the Standard and Final ANCOVA-Model for Executive Functions.

Embodied Cognitive Training and Academic Well-being

To test the hypothesis that the mean well-being scores in the intervention group, after receiving the intervention, were higher compared with the control group, an unpaired t-test was conducted. ECT can be a strength in terms of having a medium effect on social relationships (*P* = 0.049, *Cohen's d* = 0.54) after the intervention period in the intervention group (M = 2.28/5) compared to the control group (M = 2.08/5) (Table 4). For satisfaction, engagement, academic self-concept and pedagogical climate, no significant results were obtained post-I. In addition, to test the hypothesis that ECT had a positive impact on adolescence's academic well-being, a paired t-test was performed. This could not be proven (Table 4). However, *P*-values in the intervention group are considerably more towards significance compared to the control group in terms of social relationships (I: *P* = 0.08 -- C: *P* = 0.76) (Table 4).

	Pre-I			**Post-I**			**Pre- and post-I**	
	I M ± SD	C M ± SD	I–C *P* (*d*)	I M ± SD	C M ± SD	I–C *P* (*d*)	I pre – I post *P* (*d*)	C pre – C post *P* (*d*)
Satisfaction	2.98 ±0.54	3.17 ±0.60	0.45 (-0.24)	3.08 ±0.42	3.17 ±0.60	0.77 (-0.12)	0.17 (-0.15)	0.96 (0.00)
Engagement	2.77 ±0.28	2.64 ±0.26	0.21 (0.34)	2.70 ±0.27	2.65 ±0.22	0.66 (0.14)	0.39 (0.18)	0.71 (-0.03)
Academic self-concept	2.89 ±0.26	2.87 ±0.29	0.85 (0.05)	2.80 ±0.29	2.99 ±0.31	0.13 (-0.45)	0.28 (0.23)	0.29 (-0.28)
Social relationships	2.13 ±0.14	2.08 ±0.38	0.46 (0.12)	2.28 ±0.23	2.08 ±0.29	**0.049** (0.54)	0.08 (-0.56)	0.76 (0.00)
Pedagogical climate	2.82 ±0.41	3.12 ±0.31	**0.04** (-0.58)	2.93 ±0.47	3.16 ±0.40	0.16 (-0.37)	0.13 (-0.18)	0.74 (-0.08)

Note. Pre-I = pre-intervention, Post-I = post-intervention, I = Intervention group, C = Control group, M = mean well-being scores /5, SD = standard deviation, P = significant when <0.05, d = Cohen's d effect size: small effect size 0.20; medium effect size 0.50; large effect size 0.80.

Table 4: Average Academic Well-being Scores in Pre- and Post-Test.

Furthermore, an ANCOVA-model was constructed to correct for possible main and interaction effects. The standard model included following covariates: BMI, sex, number of received trainings, and group (intervention versus control). 'The mean well-being scores pre-intervention' was chosen as the independent variable and 'number of received trainings' was chosen to be included in the final model as covariate. This is because both variables showed respectively large and medium significant effects with the mean well-being scores after intervention (Table 5). ECT can be a strength in terms of having a large effect on satisfaction (η^2G = 0.84, M pre-I = 2.98/5, M post-I = 3.08/5), and a medium effect on social relationships (η^2G = 0.48, M pre-I = 2.13/5, M post-I = 2.28/5) and pedagogical climate (η^2G = 0.47, M pre-I = 2.82/5, M post-I = 2.93/5) (all *P* < 0.01) (Table 5).

Standard model: Independent variable: mean well-being scores pre-I, tested covariates: all			
	P	***F***	**η^2G**
Mean well-being scores pre-I	**<0.01**	77.11	0.84
Sex	0.78	0.09	<0.01
BMI	0.62	0.26	0.02
Training	**0.04**	6.10	0.47
Group	0.06	4.29	0.22
Sex*BMI	0.11	2.97	0.17
Sex*training	0.15	2.28	0.13
Sex*group	0.19	1.89	0.11
BMI*training	0.41	0.71	0.05
BMI*group	0.39	0.77	0.05
Training*group ; Sex*BMI*training ; Sex*training*group; Sex*BMI*group ; BMI*training*group ; Sex*BMI*training*group	NA	NA	NA

Final model: Independent variable: mean well-being scores pre-I, covariate: number of received trainings					
Effect between	***P***	***F***	**Mean score pre-I ± SD**	**Mean score post-I ± SD**	**η^2G**
Satisfaction pre- and post-I	**<0.01**	77.11	2.98/5 ±0.54	3.08/5 ±0.42	0.84
Social relationships pre- and post-I	**<0.01**	13.80	2.13/5 ±0.14	2.28/5 ±0.23	0.48
Pedagogical climate pre- and post-I	**<0.01**	13.34	2.82/5 ±0.41	2.93/5 ±0.47	0.47

Note. Pre-I = pre-intervention, Post-I = Post-intervention, Mean well-being scores /5, P = significant when <0.05, F = variance ratio, η^2G = generalized eta squared effect size based on Pearson's r: small effect size 0.10; medium effect size 0.30; large effect size 0.50.

Table 5: Significant Outcome Measures of the Standard and Final ANCOVA-Model for Academic Well-being.

Embodied Cognitive Training and Learning Outcomes

A paired t-test was conducted to test the within-group hypothesis if ECT had a positive impact on the mean learning outcomes scores post-I compared with pre-I. Significant results for Biology were obtained for both the intervention (*P* = <0.01) and control group (*P* = 0.049) with clear differences in effect sizes (*Cohen's d* = 0.59 intervention group, *Cohen's d* = -0.25 control group) (Table 6). In addition, an unpaired t-test was conducted to test the between-group hypothesis: does ECT had a positive impact on the mean learning outcomes scores in the intervention group compared with the control group? This could not be confirmed since no significant results were obtained for French, Biology and Geography (Table 6).

	Pre-I			**Post-I**			**Pre- and post-I**	
	I M ± SD	C M ± SD	I–C *P* (*d*)	I M ± SD	C M ± SD	I–C *P* (*d*)	I pre – I post *P* (*d*)	C pre – C post *P* (*d*)
French	5.40 ±1.64	6.30 ±2.10	0.99 (-0.34)	5.69 ±2.24	5.00 ±2.14	0.49 (0.22)	0.97 (-0.10)	0.52 (0.43)
Biology	8.50 ±0.81	7.30 ±1.80	**0.01** (0.61)	7.62 ±1.24	7.90 ±1.53	0.69 (-0.14)	**< 0.01 (0.59)**	**0.049** (-0.25)
Geography	7.20 ±0.94	7.00 ±0.95	0.58 (0.15)	7.80 ±1.02	7.50 ±1.34	0.47 (0.18)	0.12 (-0.43)	0.17 (-0.30)

Note. Pre-I = pre-intervention, Post-I = post-intervention, I = Intervention group, C = Control group, M = mean learning outcomes /10, SD = standard deviation, P = significant when <0.05, d = Cohen's d effect size: small effect size 0.20; medium effect size 0.50; large effect size 0.80.

Table 6: Average Learning Outcomes in Pre- and Post-Test.

Possible main effects and interaction effects were examined within the intervention and control group by building an ANCOVA-model. The standard model included following covariates: BMI, sex, number of received trainings, and group (intervention versus control). The 'mean scores of learning outcomes pre-I' was only included in the final model since no covariate and only this variable demonstrated a significant medium effect (*P* < 0.01, η^2G = 0.40) with the mean scores of learning outcomes post-I (Table 7). ECT had a small effect (*P* = 0.04, η^2G = 0.22) on the mean scores of French post-I in the intervention group (M = 5.69/10) compared with pre-I (M = 5.40/10) (Table 7). In addition, the number of received trainings had a large effect (*P* < 0.01, η^2G = 0.67) on the mean scores for Geography in the intervention group after intervention (increased score of 0.6/10) (Table 7). Lastly, ECT was not a strength in terms of having a medium effect (*P* < 0.01, η^2G = 0.40) on the mean scores for Biology post-I in the intervention group (M = 7.62/10) compared with pre-I (M = 8.50/10) (Table 7).

Standard model: Independent variable: mean learning outcomes pre-I, tested covariates: BMI, sex, number of received trainings and group			
	P	***F***	**η^2G**
Mean learning outcome scores pre-I	**< 0.01**	10.46	0.40
Sex	0.40	0.74	0.04
BMI	0.08	3.51	0.18
Training	0.21	1.68	0.10
Group	0.06	3.95	0.20
Sex*BMI	0.15	2.27	0.12
Sex*training	0.46	0.58	0.04
Sex*group	0.33	1.02	0.06
BMI*training	**0.03**	5.83	0.27
BMI*group	**0.03**	5.84	0.27
Training*group ; Sex*BMI*training ; Sex*training*group ; Sex*BMI*group ; BMI*training*group ; Sex*BMI*training*group	NA	NA	NA

Final model: Independent variable: mean learning outcomes pre-I, covariate: /					
Effect between	***P***	***F***	**Mean score pre-I ± SD**	**Mean score post-I ± SD**	**η^2G**
Biology pre- and post-I	**< 0.01**	10.46	8.50/10 ±0.81	7.62/10 ±1.24	0.40
French pre- and post-I	**0.04**	4.79	5.40/10 ±1.64	5.69/10 ±2.24	0.22
Geography post-I and number of received trainings	**< 0.01**	16.52	7.20/10 ±0.94	7.80/10 ±1.02	0.67

Note. Pre-I = pre-intervention, Post-I = post-intervention, Mean learning outcomes /10, P = significant when <0.05, F = variance ratio, η^2G = generalized eta squared effect size based on Pearson's r: small effect size 0.10; medium effect size 0.30; large effect size 0.50.

Table 7: Significant Outcome Measures of the Standard and Final ANCOVA-Model for Learning Outcomes.

Discussion

The current study examined whether ECT had a positive effect on executive functions, academic well-being, and learning outcomes among adolescents in a classroom context. Improvements for these three domains were expected in the intervention group. Despite no significant results were obtained within the (un)paired t-test analyses (expect for social relationships), the ANCOVA analyses resulted in significant effects in terms of working memory, satisfaction, social relationships, pedagogical climate, and learning outcomes for French and Geography in the intervention group because of ECT.

During the initial ECT, the researchers noted that some adolescents had difficulty with the dual-task training: some had difficulty with the motor or cognitive subtask, while others had difficulty with combining them both successfully. Over time, the integration of the dual task training went significantly better, probably because of better control in the brain and neuroplasticity due to new connections (synapses) between the cerebellum, basal ganglia and prefrontal cortex (Olszewska et al., 2021). These synapses can be made quite rapidly since the adolescent brain is plastic. In response to a change in synapses – as a result of learning - the brain will begin to reorganize, enlarge, and works more efficiently (Lundy-Ekman, 2018). In addition, these changes include dynamic reconfiguration of neural connections, myelination – which is important for message transfer -, and neurogenesis – i.e., manufacturing new neuron cells (Olszewska et al., 2021). Furthermore, low to moderate continuous physical activity leads to improved maturation of the myelin sheath and a thicker myelin sheath, causing nerve conduction of stimuli will be faster and more efficiently send out within the neural circuit (Bobinski et al., 2011). During the dual-task training, adolescents were continuously challenged with new or difficult subject matter (challenging cognitive skills) and more difficult SenseBall© exercises (challenging motor skills). Research by Diamond (2000) states that the prefrontal cortex and the cerebellum are activated during cognitive and motor tasks (Diamond, 2000).

No effect of ECT was found in current study on impulse control, alertness and attention. ECT did show small positive effects within the Reading Span Test (working memory). However, the adolescents in the intervention group took longer to perform the Operational Span Test and Mixed Span Test, both also considering working memory. During the course of the executive function tests proceedings, the researchers noted that most of the students had difficulty maintaining focus and attention. This was mainly because of conversations between other students who finished earlier, eventually causing classroom noise. Possibly this explains why no (strong) effect could be shown in current research of ECT on alertness, attention, and working memory (Retalis et al., 2014). Besides, a review concluded that the improvement of executive functions depends on the time of practicing (Diamond & Ling, 2016). Our planned six-week intervention in the current study was reduced by one week because of the Covid-19 measures. Hence, positive effects on executive functions of ECT in our healthy adolescence population, are probably negligible.

Social relationships, which is covered in this research by well-being, improved slightly after the intervention period. This is in line with the subjective findings of the researchers during the interventions' implementation: the students interacted with each other and were motivated to perform the ECT. Previous literature found a correlation between good friendly relationships in a school context and beneficial effects on mental health (Ueno, 2005). Moreover, ECT showed positive effects in terms of satisfaction and pedagogical climate. Within this context, Rita Dangol and Milan Shrestha (2019) examined the influence of readiness to learn on well-being scores and learning outcomes in high school students. They found a significant relationship between willingness to learn and achieving high learning outcomes (Dangol & Shrestha, 2019). This is in line with research by Michel Bruyninckx - founder of the Michel-Bruyninckx-Method (MBM) - since he investigated the principle of ECT in a soccer context by using a similar experimental design to the present study. He concluded that ECT stimulates willingness to learn (Bruyninckx, s.d.).

ECT had a small positive effect on the average scores for French. Noteworthy, the number of ECT sessions had a medium effect on Geography learning outcomes. These findings are in line with previous research showing a positive relationship between ECT and these outcome measures in elementary school children (Mcclelland et al., 2014. Have et al., 2016). Contents of Biology were less successfully remembered during the ECT since ECT did not have a positive effect on the average scores for Biology. This result was not expected since Biology as well as Geography are both scientific courses. Because of the Covid-19 measures, the scheduled Biology tests at the intervention period end were reduced to one test and this test was taken one month after the intervention period ended.

Strengths and Limitations

Previous research has not focused on embodied cognition in adolescents, which makes the current study innovative and unique. The executive function tests, the well-being questionnaire and 50-minute training sessions were given by the researchers themselves, allowing for sufficient control. In general, there was little result from the t-test analyses, probably because of the low sample size. Once an ANCOVA model was built in which there was controlled for independent variables and covariates, significant effects were found. Besides, due to the Covid-19 pandemic, students were half-time physically present at school causing the intervention- as well as the control group to contain fewer participants. That on its turn influenced the statistical power. Furthermore, the Easter vacation was extended, causing the planned six-week intervention period to be brought back to five weeks. Hence, half of the students of the control group were present during the executive function and well-being test administration at the end of the intervention period. If the intervention period could take longer with more participants, we might have obtained more significant effects and results. Finally, due to strict restrictions on leisure activities and physical contact, students' well-being could be negatively affected. This is in line with research that argues that feeling lonely has a particularly negative impact on adolescents because they are in a sensitive period where socializing with friends is an important part of their development (Loades et al., 2020). In addition, Von Soest and colleagues (2020) show that adolescents have lower life satisfaction due to Covid-19 pandemic concerns (Von Soest et al., 2020). Finally, the intent was to collect data of the previous education of the students’ mother (or guardian) and the financial background of the family. The participating school could not provide the desired information due to privacy regulation. Research by Najman et al. (2004) has shown that a significant predictor of mental well-being and cognitive development comes from the financial background of the family (low income) and low socioeconomic status of the mother (Najman et al., 2004).

Conclusion

Embodied cognition has been extensively studied in toddlers and elementary school children, but not yet in adolescents. Current pilot study and explanatory research was implemented as ECT and focused on the target group of adolescence, which made the study innovative. There can be concluded that ECT showed positive but limited effects on adolescents' working memory, satisfaction, social relationships, pedagogical climate and learning outcomes for French and Geography. Besides, ECT fits closely with recent educational visions in which the curriculum is less teacher-driven, but starts more from a student-centred educational vision. This educational vision takes into account the students and positive psychology within the school. Our research is of social importance as it provides more insights into the cognitive processes entangled with the learning process in adolescents.

Future research should, on one hand, focus on a longer intervention period and larger study population (with and without developmental disorders) resulting in stronger associations and a higher power of the study. As executive functions include important processes, such as working memory and focus, the direct link between executive functions and learning outcomes should be investigated in future research by studying the executive function test outcomes and combine these results with the learning outcomes. Previous research concluded that different aspects of executive functions can be important for learning science courses (Rhodes et al., 2013). Also, more in depth research is necessary about which courses and course contents match with the education model of embodied cognition. Finally, the importance of classroom space and design should be explored. Current research could be repeated in a typologically diverse school setting; e.g., in large classrooms or a covered area with the possibility to use a projector to project the course matter. However, not every school has the ability to provide these diverse settings. Hence, future research should consider the optimal use of classrooms and classroom-design in an ECT setting so it can be implemented in every school context.

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Appendix A: Description Executive Function Tests

The Stop-Signal Test (duration five minutes, one practice round, four experimental rounds) gave an indication of the adolescent's response inhibition and impulse control. During the 'go task', students had to correctly press the left or right arrow key as quickly as possible in response to the corresponding arrow direction displayed on the screen. During the 'stop task', the arrow turned red after a variable delay, implying that the students were not allowed to press the corresponding arrow key (Figure 2).

Figure 2: Visualization Stop-Signal Test.

The ANT (duration five minutes, one practice round, one experimental round) was performed to have an indication of participant's alertness and attention. Five arrows were shown on the screen of which students had to indicate the corresponding direction of the middle arrow as quickly as possible with the right or left arrow key (Figure 3).

Figure 3: Visualization Attention Network Test.

The AST (duration 30 minutes, one experimental round) is a collection of the Reading, Operational and Mixed Span Test. These tests give an indication of the students' working memory. During the Reading and Mixed Span Test, students had to rate (two to six) sentences for credibility; during the Operational Span Test they had to assess (two to six) calculations. Hereafter, students had to respectively remember words, letters or numbers after each sentence or calculation, which they had to recall later. Each test consisted of fifteen series. An example is given in figure 4 in Dutch.

Figure 4: Visualization Attention Span Test.

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