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The influence of physical activity on the creativity of 10 and 11-year-old school children

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ABSTRACT

The benefits of physical activity in terms of physical and cognitive health are increasingly being studied and analyzed. However, divergent thinking has been scarcely studied in relation to the exercise performed. This study aimed to analyze whether there is a relationship between creative ability, intensity and amount of physical activity in 10–11 year old children. This research is framed within an ex post facto, descriptive, cross-sectional and correlational approach. The sample of this study consisted of 169 participants (82 boys and 87 girls), from a public Primary School center in southern Spain, aged between 10 and 11 years ($M \pm$ SD: age = 10. 48 $\pm$ 0.50 years). The amount and intensity of physical activity performed by students was measured by accelerometry, and the Torrance Test of Creative Thinking was used to evaluate the dimensions of creativity Originality, Fluency, Elaboration and Flexibility. All data collected was analyzed, using IBM-SPSS Statistics. Our results have revealed a correlation between the Cognitive Fluency, Originality and Cognitive Flexibility dimensions with moderate-vigorous physical activity. It is concluded that the "key to creativity" may depend on a combination of cognitive, social and family factors (among others). Although there is a tendency for a positive correlation between physical activity and creative ability, more studies are needed to better consolidate these assumptions.

1. Introduction

1.1. *Creativity concept and embodied cognition definition of creativity*

Every day, in our society, we are forced to face problems of various kinds. We often have to adapt and look for original solutions to the different problems that occur, therefore creative capacity plays an important role in our lives (Barbot, Besancon & Lubart, 2011; Lupu, 2012).

From minute displays of novelty, to everyday big problem-solving in settings as disparate as a company or a classroom, including

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efforts on different scales to foster ingenuity, creativity has become a widely propagated phenomenon that engenders great respect in modern society (Frith, Loprinzi & Miller, 2019). Thus, creative cognition represents an important feature in a variety of everyday life contexts and specific domains (Oppici, Frith & Rudd, 2020).

Thus, knowing what creativity is and how to develop it are questions of interest in many fields of social sciences and are regularly addressed by educators, teachers and psychologists. However, only defining the concept of "creativity" is a research topic in itself (Lubart, 2003), being difficult to limit to a singular and operational definition the illusory concept of creativity (Frith, Ryu, Kang & Loprinzi, 2019; Runco & Jaeger, 2012).

Though, to assume that there is no certain consensus, or at least some core elements for defining creativity, would be incorrect (Gardner, 2006; Sawyer, 2011; Shaw et al., 2022; Stein, 1953; Sternberg, 2006). Currently, scholars suggest that for a work or response to be considered creative it has to be unexpected, unusual, original, surprising, interesting, novel, relevant, and highly useful and valuable (Sternberg, 2006; Sternberg & Lubart, 1996).

Other researchers have defined creativity as a broad construct that encompasses the ability to break traditional or obvious patterns of thinking, adopt new or higher-order rules, and generate new solutions to specific problems (Dietrich & Kanso, 2010; Sawyer, 2011).

However, despite growing evidence of the importance of an embodied or movement-based approach to understanding creativity, and the embodied perspectives on cognition that argue that body movement plays a key and active role in the development of creative ideas, few creativity theories still incorporate this aspect (Frith et al., 2019; Oppici et al., 2020).

On an embodied account of cognition, creative development happens as a result of the acting on and within an environment (Harbourne & Berger, 2019). Along these lines, the 4E cognition approach to creativity (embodied, embedded, enactive, and extended) suggests that, beyond idea generation, the role of creative cognition is to guide action, and argues that human cognition is a dynamical system encompassing brain/mind, body, and world/environment (including objects, materials, and artifacts developed by humankind) (Gubenko & Houssemand, 2022; Malinin, 2019; Shapiro & Stolz, 2019). In this way, how we learn and develop expertise is shaped, constrained, and enacted through exploration and interaction with our physical environment.

Despite the potential of embodied cognitive science to generate new insights into how people acquire creative skills, the field of creativity research has not paid much attention to the role of the body or its physical context. Given that creative process research has made little progress in recent years and the lack of relevance for informing educational practices or learning environments continues, researchers may benefit from adopting an action-oriented and physically situated perspective (Malinin, 2019). Furthermore, understanding which mental and environmental factors may promote or inhibit creative thinking processes is critical to setting up models that adequately address creative cognition across domains (Matheson & Kenett, 2020).

Below, we review research findings that are consistent with this stream on the functional role played by the motor system in the generation of creative thoughts. Thus, the purpose is not to comprehensively review the literature on creativity, but to highlight a subset of the literature that focuses on the effects of motor processes in creativity tasks.

1.2. Creativity as a trainable high-order embodied cognitive function

Higher-order thinking, a concept based on learning taxonomies, is used today to describe learning behaviors and differentiate levels of cognition (Malinin, 2019). At the same time, we can establish that the executive function is a higher order cognitive function which objective is to simplify adaptation to new situations through the control or modulation of more basic cognitive skills that can be learned through repetition and practice (Etnier & Chang, 2009). Among the most commonly considered executive functions, we can find planning, metacognition, inhibition, cognitive flexibility, cognitive fluency and working memory (Diamond, 2013; Kofler et al., 2019).

Nowadays, the revised Bloom's Taxonomy describes creativity as the most complex (highest-order) process in the hierarchy of knowledge (Malinin, 2019), thus requiring higher-level components of cognitive function supported by the executive control network, such as working memory, inhibitory control, goal-consistent behaviors, and cognitive flexibility (Frith & Loprinzi, 2018). To these we should add other cognitive factors including problem identification, selective coding or ability to select related environmental information, divergent thinking, evaluation of ideas and associative thinking (Khalil, Godde & Karim, 2019).

Of all of them, divergent thinking is perhaps the one most closely related to creativity, and is even established as a tool that allows predicting creative potential. Divergent thinking is considered to be composed of four capacities: mental fluency, cognitive flexibility, originality of thought and capacity for elaboration (Allen & Tomas, 2011; Runco, Mumford, Hunter & Bedell-Avers, 2008).

Fluency (FLU) is understood as a person's ability to come up with as many ideas as possible to solve a problem (Krumm, Aranguren, Arán Filippetti & Lemos, 2016) and differs from flexibility (FLE) in that the latter refers to the different approaches that the person uses to solve the same problem (Ferrándiz García, Ferrando, Soto, Sáinz & Prieto, 2017). Originality (O) is the ability to produce unusual or unique responses, and elaboration (ELA) consists of the ability to improve and refine these responses (Humble, Dixon & Mpofu, 2018).

An evolutionary perspective of development asserts that executive function evolved from fundamental sensorimotor systems that preceded higher order cognitive functions. These embodied approaches to executive function are particularly relevant to creativity, as a wealth of evidence suggests that early acquisition of motor skills is positively associated with cognitive development, and that executive function appears to be instrumental in the execution and understanding of creative activities (Frith et al., 2019; Oppici et al., 2020).

Based on this theory, the paradigm of embodied cognition argues that cognition is for action, being an organism's body, in some sense, integrated in its own cognitive processing due to the tight connection between cognitive processing and brain areas associated with physical motion (Malinin, 2019; Shapiro & Stolz, 2019).

It is for all these reasons that, because embodied movement reinforces physical interactions that influence the cognitions underlying creative behavior, physical activity takes on an essential role in the cognitive development of creativity, with body movements and interactive play being able to uniquely facilitate creative thinking from early childhood onwards (Frith et al., 2019).

1.3. Physical activity as a factor influencing creativity. Role of schools

Promoting and teaching creativity is a complicated matter, as people are generally attracted to and use possibilities to guide their movement that are commonly accepted in the society. In other words, they follow the norm, do what is normally done and act within their comfort zone (Oppici et al., 2020). Perhaps this is why, although everyone has capacity to be creative and it is understood to be a teachable skill, specific pedagogical practices that lead to creativity have not been identified (Malinin, 2019). It is known that several internal and environmental factors influence the creative process. Internal factors include intelligence, cognition, personality (Kandler et al., 2016; Kandler, Zimmermann & McAdams, 2014; Simonton, 2014), self-concept (Bournelli, Makri & Mylonas, 2009), motivation (Ren, Wang, Jiang & Ran, 2017), and gender (Duh & Büdefeld, 2018). These factors are joined by other conative ones related to personality, such as perseverance, tolerance to ambiguity, openness to new experiences (Barbot et al., 2011; Mumford & Gustafson, 1988), self-acceptance, self-control or self-confidence (Selby, Shaw & Houtz, 2005).

Regarding the environmental factors that may favor an individual's creativity, the following have been studied: parents and their professions (Grao-Cruces, Loureiro, Fernández-Martínez & Mota, 2016; Sternberg, Grigorenko & Singer, 2004), teaching methods (Besancon & Lubart, 2008), school and family environment (Deng, Wang & Zhao, 2016) and even birth order (Lubart, 2003). Given that it is very difficult to act on the internal factors, the study of external factors could help to plan educational strategies that favor creative potential.

One of the environmental factors that could influence the conative factors and that has rarely been studied is the physical activity performed, its quantity, intensity and type (Frith et al., 2019). Research conducted in recent years has found significant relationships between physical practice and various cognitive skills fundamental to creative thinking (Chaddock, Pontifex, Hillman & Kramer, 2011; Li, O'Connor, O'Dwyer & Orr, 2017; Scudder et al., 2014; Xue, Yang & Huang, 2019), stating that physical activities promote creativity (Frith et al., 2019; Jung, Kim, Loprinzi & Kang, 2021; Kim, 2015; Lupu, 2012; Piya-amornphan, Santiworakul, Cetthakrikul & Srirug, 2020; Roca, Ford & Memmert, 2018).

The explanations for these positive effects of physical activity on creativity could be several. Some authors have reported that aerobic exercise can cause permanent changes at various levels, including morphological and functional changes in various brain areas, and these changes have a significant effect on systems which are known to play a critical role in the creative process (Molteni, Ying & Gómez-Pinilla, 2002; Ratey & Loehr, 2011). In addition, other studies informed that moderate to vigorous intensity physical activity (MVPA) stimulates brain regions capable of producing novel results and goal-directed behavior (Beaty et al., 2014; Colombo, Bartesaghi, Simonelli & Antonietti, 2015), and induce the release of neurotransmitters that plays an important role in cognitive control, attention, inhibition and creative ability (Frith & Loprinzi, 2018; Köhncke et al., 2018).

A strong test of the functional role of the motor system in creative thinking requires direct manipulation of motor activity during the generation of creative responses. Indeed, explicitly intervening by having individuals engage in a motor task that triggers the activation of the motor system influence their creative performance. A growing body of research across various creativity domains states this is the case (Matheson & Kenett, 2020). Going beyond, recently, neuroscience analyses have also implicated motor regions in creative thinking. The authors show that sensorimotor brain regions have a positive relation with creative ability and highlighting the importance of integrating sensory and motor information in generating creative responses (Matheson & Kenett, 2020).

However, despite the evidence, too little work to date has explored the potential of physical activity to influence embodied creativity or performance on well-established components of cognitive creativity (Frith et al., 2019), and the vast majority lacks solid foundations and methodological quality. In addition, very few have focused on an school context nor on a crucial age interval such as the completion of the Primary educational stage (Frith et al., 2019).

These described parallels between executive function, divergent thinking, and creative output in this transition period in formal education warrant further examination (Frith et al., 2019). For this reason, this research focuses on analyzing the influence of physical activity on creativity, using the school context as a framework and focusing on children in the last cycle of primary education.

The reason why research in the school setting is important is because schools are an ideal natural environment for effective interventions due to the ability to maximize their reach, as children spend extended and regular periods of time in them, have valuable and numerous resources, and ensure access to the majority of the child population (Frith et al., 2019).

On the other hand, this age group (10–11 years old) has been chosen due to the fact that creativity tends to increase from preschool through early adolescence; but it is interrupted by a succession of "creative routes," the first of which parallels entry into elementary school. Upon entering primary school, as students are taught how to learn and apply their knowledge to meet the needs of an existing sociocultural infrastructure, originality can be subverted into the acquisition of verifiable knowledge schemas. Given this transition from cognitive exploration to cognitive alignment throughout childhood, researchers have suggested that a decline in creativity that begins in the fifth year of life may peak at eleven when they complete elementary school (Frith et al., 2019).

In addition, early adolescence is the end of one stage and the beginning of another, both at a maturational and scholastic level, emerging as a key period of brain maturation (Laube, van den Bos & Fandakova, 2020) in which there is a transition between childhood and adulthood, causing profound changes in brain structure and an increase in neuronal plasticity (Blakemore, 2012; Johnson, Blum & Giedd, 2009). Therefore, before entering the next maturational phase, it will be useful to observe and analyze the levels of creativity developed by students during this period (Sali, 2019) and how this may be related to another factor of change at the physical-motor level, such as physical activity (Santos & Monteiro, 2021).

Given the above, studies like this are necessary to analyze the relationship between physical activity and creativity in specific circumstances and contexts (such as schools), reaching a greater and better understanding of how specific programs and interventions can promote creativity from childhood onwards. In this sense, knowing the effect that the practice of physical activity has on creativity at these ages is of vital importance in the planning of educational programs.

Therefore, the aim of this research was to determine whether there is any significant relationship between the amount and intensity of physical activity performed by students aged ten and eleven years and creativity in its various dimensions. In this sense, the present study is based on the hypothesis that there is a positive relationship between physical activity, especially that of moderate to vigorous intensity, and the different components of creativity, so that the most physically active students will also be more creative.

The main contribution of this work is the use of accurate and objective measures of physical activity through accelerometry together with the assessment of creativity using the Torrance Test of Creative Thinking, to check whether there exist any association between the amount or different intensities of physical activity and the various dimensions of creative thinking or creativity in general.

2. Materials and methods

2.1. Study design

This research is framed within the empirical paradigm, which aims to answer the study hypothesis through the quantitative method (Cox, 2019), where the phenomenon is explained and predicted through numerical data. With respect to data collection, management and analysis, the study has an ex post facto, descriptive (since information on the population and the study situation is accurately described), cross-sectional and correlational (analysis of prediction, comparison and relationship between several variables) approach (Ato, López-García & Benavente, 2013).

2.2. Recruitment, eligibility, participants and consent to participate

For this study we selected a public school in the province of Malaga (Spain) in which the third cycle of primary education is taught (10 to 11 years, 5th and 6th grades of primary school). All children in this educational cycle who wished to participate were able to do so, although those who did not meet the age criteria or who had a diagnosed physical or cognitive deficit were subsequently excluded.

The classes were recruited through an intentional or convenience non-probabilistic sampling, but not from specific individuals. Therefore, the design of the present research was a randomized cluster design, with children in the same school and class sharing the same environment.

The participation of 7 classes from the last cycle of primary school (182 children aged 10 and 11), divided into 4 classes of 5th grade and 3 classes of 6th grade, was requested. Consent was obtained from the parents or guardians of 179, of whom 169 took the anthropometric tests, 166 also took the creativity test, and 141 took all the tests and met the requirements established in terms of the minimum accelerometry recording time.

Finally, data were obtained from 169 participants (82 boys and 87 girls), aged between 10 and 11 years ($M \pm$ SD: age = 10. 48 $\pm$ 0.50 years; weight = 41.61 $\pm$ 10.73 kg; height = 145.63 $\pm$ 8.28 cm; body fat percentage = 22.83 $\pm$ 7.87%; muscle percentage = 73.29 $\pm$ 7.91%; Impedance = 612.44 $\pm$ 80.57; Body Mass Index = 19.47 $\pm$ 3.83 kg/m^2).

All procedures were examined and validated by the school principal, who provided the corresponding written collaboration agreements, as well as by the families. Written informed consent from the parents or guardians was obtained before the children joined the study. All parents received a document detailing the aims, limitations and risks of the study, the methodology and procedures used and the activities to be performed before being asked to sign the consent forms. In any case, participation was always voluntary and confidentiality about the identity of the participants was always guaranteed. For this purpose, all personal data provided were anonymized using a unique identification number, and all printed data were securely stored in locked filing cabinets and electronic information stored on password-protected university computers. Lastly, the tests were conducted following the ethical guidelines set by the Faculty of Education Sciences of the University of Malaga, the Declaration of Helsinki (World Medical Association, 2013), and Oviedo Convention.

2.3. Instruments and testing

We employed the Torrance Test of Creative Thinking (Torrance, 1974) in its figurative version (form B), as it is a widely used tool for the estimation of divergent thinking (Almeida, Prieto, Ferrando, Oliveira & Ferrándiz, 2008; Frith et al., 2019; Oliveira et al., 2009) and presents a high reliability (with Spanish sample, the reliability reported for this test was Cronbach's α = 0.82) (Prieto Sánchez, López Martínez, Ferrándiz García & Bermejo García, 2003).

The test evaluates, by means of drawings and compositions, the creative capacity of the individual through its dimensions, which are O, referring to the novelty and unconventionality of the answers given; FLU, based on the number of answers given by the participants; ELA, or the ability to enrich, embellish and improve a creative production with a high level of detail; and finally, FLE, understood as the ability to propose a great variety of answers that are different from each other (Ferrándiz García et al., 2017; Humble et al., 2018; Krumm et al., 2016).

This instrument consists of three tests or "games" that participants must complete in 30 min (10 min for each test). In the first one, called "Picture Construction", the child is asked to make a drawing from a given shape and give it a title (if the child does not give a title to his creation, it cannot be scored). The skills assessed are O (novel responses) and ELA (number of details to improve the drawing). The second game, "Picture Completion", consists of 10 strokes or incomplete shapes from which the child has to draw a picture and give them a title. ELA (number of details), O (unusual responses), FLE (variety of responses given) and FLU (number of drawings made) are evaluated. Finally, the third test, "Parallel Lines", consists of 30 pairs of parallel lines from which as many drawings as possible must be made. This test measures FLU (ability to make multiple associations), FLE (ability to change structure in compositions), O and ELA to make novel drawings and add details (Ferrando et al., 2007; Prieto Sánchez et al., 2003).

The test was developed and corrected according to the application instructions and correction criteria indicated in the manual. Based on the adaptations made by Prieto Sánchez et al. (2003) and Jiménez-González, Artiles-Hernández, Rodríguez-Rodríguez and García-Miranda (2007), the corresponding emptying sheet was used and test scoring was done by hand, keeping in mind that careful attention to the manual is required to obtain reliable results.

In the case of the O dimension, for subtest 1 "Picture Construction", six ranges of variability were applied according to the drawing made using the given shape: 0 points for human head, egg, flower, sun and cloud; 1 point if a green space, a tree or a car is drawn; 2 points for leaves, foliage or branches; 3 points for drawings of human body, hats, the body of an ostrich or birth from the hatching of an egg; 4 points if the child draws parts of the face, animal bodies, a ball, a rocket, a planet, an alarm clock, a martian, a melon, a boat or a wheel; and 5 points for other responses.

To assess and score FLE, 69 different categories of objects were considered, ranging from "accessories-jewelry", "food" or "angels", to "transport by sea", "air", "land" or "clothing", to "toys", "letters of the alphabet" or "books", to name a few examples. As for ELA, criteria such as "unnecessary details or decoration", "adding color to the drawing", "drawing shadows", "variations in the drawing of the same object" and "elaboration of the title given to the drawing" were considered. FLU (subtests 2 and 3) was assessed according to the number of drawings made.

The instruments used to determine the anthropometric variables were a Seca 213 portable stadiometer, with a graduation of 1 mm and a measuring range of 20 - 205 cm, and a Tanita SC 330 S portable bioelectrical impedance analyzer for the evaluation of body composition. This process was carried out according to its use in clinical practice (Kyle et al., 2004). As a complementary variable, partly related to the practice of physical activity, hand grip strength was assessed by digital dynamometry, using the Takei T.K.K.5401 GRIP-D handgrip dynamometer (Takei Scientific Instruments Co., Ltd, Tokyo, Japan). All measurements were performed alternatively 3 times with no rest. For each measurement, the participant was asked to squeeze the dynamometer for 3 s. The peak value of strength was recorded (Amaral, Mancini, Júnior & J., 2012).

To estimate the amount and intensity of physical activity, triaxial accelerometry was used as a widely recognized method for this purpose, using the ActiGraph wGT3X-BT® accelerometer (Actigraph, Pensacola, FL, USA). This device is validated to quantify physical activity (Santos-Lozano et al., 2013). Participants' physical activity was recorded for 7 consecutive days following the recommendations proposed in previous studies (Frömel, Stelzer, Groffik & Ernest, 2008; Trost, Mciver & Pate, 2005). The device was placed on the left hip over the iliac crest using an adjustable band (Evenson, Catellier, Gill, Ondrak & McMurray, 2008). A recording time of $\geq$ 10 h/day and 5 days (4 during the week and 1 on the weekend) was considered valid (Matthews, 2008). For the management and processing of the records, the Actilife 6.0 Software (Actigraph) was used. The data were stored at an epoch of 1 s. The cut-off points selected were those proposed by Evenson et al. (2008): Sedentary $\leq$ 100; Light physical activity $\geq$ 100; Moderate physical activity $\geq$ 2296 and Vigorous physical activity $\geq$ 4012 counts•min^{1}.

As a result, we will be provided with data related to the time dedicated by the participants to each of the different levels of intensity of physical activity, as well as the amount of MVPA performed (as a result of the sum of moderate and vigorous physical activity) and the overall physical activity, also known as light to vigorous physical activity (LVPA), all expressed in minutes per day.

2.4. Procedures

After obtaining the permission of the school principals and the approval of the school boards, the informed consents signed by the legal guardians of the students participating in the sample were collected, also respecting the principles of the Declaration of Helsinki promulgated by the (World Medical Association, 2013).

The evaluation procedure was carried out in the Human Motricity Laboratory of the Faculty of Education Sciences of the University of Malaga between 9:00 and 11:00 in the morning. First, anthropometry data, strength assessment by dynamometry and body composition records by bioimpedance were collected. For this, the standardized protocol (Sánchez-Iglesias, Fernández-Lucas & Teruel, 2012) was taken into account.

Once these first measurements were taken, the student was asked to participate in the Torrance Test of Creative Thinking. This questionnaire consists of three parts of 10 min each. For the administration of the test, the instructions contained in the test manual (Torrance, 1966) were followed, letting the participants know that this test was not a school exam. In addition, participants were informed that they had enough time, that anonymity was guaranteed and that they should express themselves freely.

2.5. Data analysis

In order to determine the parametric or non-parametric nature of the data, the Kolmogorov-Smirnov test was applied since the number of participants is greater than 50. The analysis tests of the normality of the variables revealed a non-parametric nature and correlation coefficients were calculated on this basis. Subsequently, bivariate correlation were performed to analyze the influence of the various types of physical activity on the components of divergent thinking, namely: age; size; weight; fat mass; hand grip strength; originality; fluency; elaboration; flexibility; creativity; sedentary; light physical activity; moderate physical activity; vigorous physical activity and moderate to vigorous physical activity. In order to know the effect that physical activity has on divergent thinking, a multiple regression model was carried out consisting of the different intensity thresholds of physical activity and total physical activity.

All physical activity levels and total physical activity were excluded from this analysis, except vigorous physical activity. On the other hand, variables related to creativity (e.g., originality, cognitive fluency, elaboration and cognitive flexibility) were analyzed (see Tables 1-4). The data analysis was conducted using IBM SPSS® Statistics software, version 23.0 (IBM Corp, Armonk, NY, USA), for Windows® and a statistical significance of 5% ($p < 0.05$) was defined.

3. Results

The descriptive values in the form of mean and standard deviation in minutes for the different levels of physical activity performed by the students, as well as the other values of the main study variables, are shown in Table 1.

The results indicated that the participating children spend a mean of 758.5 ± 272.1 min per day in sedentary behavior, 92.5 ± 22.0 performing light physical activity, 25.2 ± 8.3 performing moderate physical activity and a mean of 22.6 ± 10.8 performing vigorous physical. Given the above, the mean daily MVPA performed is 47.6 ± 18.1 min, while LVPA is 140.3 ± 41.1 min per day (Table 1).

If we consider the anthropometric variables, we observe that the mean size of the participating students is 145.6 ± 8.3 cm, with a mean weight of 41.7 ± 10.7 cm and a mean percentage of registered fat mass of 22.8 ± 7.9 kg. This makes the mean BMI for this group 19.4 ± 3.8, which also presents a mean hand grip strength of 39.2 ± 8.5 (Table 1).

Regarding the variables related to creativity, the mean scores obtained in the Torrance Test of Creative Thinking for the different components were 78.0 ± 29.7 for O, 19.1 ± 6.6 for FLU, 22.4 ± 10.1 for ELA and 15.6 ± 5.2 for FLE. The mean score for overall creativity was 135.1 ± 43.5 (Table 1).

Bivariate correlation coefficients (CI = 95%) among measures are presented in Table 2. Regarding age, anthropometric variables, body composition and hand grip strength, we can affirm that no correlations were found with cognitive variables. However, we can highlight some correlations that can be remarked (Table 2). Hand grip strength was significantly and negatively related to size ($r = -180$, $p < 0.05$), weight ($r = -527$, $p < 0.01$) and% fat mass ($r = -446$, $p < 0.01$), but it was not related to any of the components of creative thinking.

Regarding physical activity and sedentary behavior, we can highlight that the variable SED (sedentary) was positively and significantly related to age ($r = 241$, $p < 0.01$), size ($r = 126$, $p < 0.05$), weight ($r = 170$, $p < 0.01$) and% fat mass ($r = 265$, $p < 0.01$). Furthermore, light physical activity was positively and significantly related to% fat mass ($r = 115$, $p < 0.05$) and vigorous physical activity was negatively and significantly related to age ($r = 201$, $p < 0.05$) (Table 2).

In relation to the components of divergent thinking, it is shown in Table 2 that sedentary behavior was not significantly related to any of them. With respect to the different intensities of physical activity, there is no correlation with ELA capacity. However, vigorous physical activity is positively and significantly related to FLU ($r = 216$, $p < 0.05$), and positively and highly significantly related to O ($r = 189$, $p < 0.01$), FLE ($r = 272$, $p < 0.01$) and creativity in general ($r = 163$, $p < 0.01$).

For its part, MVPA follows the same pattern, so that it correlates positively, although less significantly, with FLU ($r = 202$, $p < 0.05$), this relationship being positive and highly significant with O ($r = 168$, $p < 0.01$), FLE ($r = 242$, $p < 0.01$) and creativity in general ($r = 154$, $p < 0.01$), as presented in Table 2.

In order to know the effect that physical activity has on divergent thinking, a multiple regression model was carried out consisting of the different intensity thresholds of physical activity and total physical activity (Table 3).

All physical activity levels and total physical activity were excluded from this model except vigorous physical activity. In Table 3 we can observe that the vigorous physical activity predictor ($B = 0.904$, B SE = 8.886, β = 0.213, $t = 2.537$, CI [0.199, 1.608]) significantly accounted for 4.5% (95% CI for R2; adjusted R2 = 0.038) of variance of creativity, F (1, 136) = 6.435, $p = 0.000$.

Finally, a multiple regression analysis was carried out for vigorous physical activity predicting components of divergent thinking

Table 1
Descriptive statistics for the analyzed variables.

	n	*Minimun*	*Maximun*	*M*	*SD*
Size (cm)	169	121.0	169.0	145.6 ± 8.3	
Weight (kg)	169	24.0	80.9	41.7 ± 10.7	
Fat mass (%)	169	9.0	46.1	22.8 ± 7.9	
BMI (kg/m^2)	169	13.0	33.7	19.4 ± 3.8	
Hand grip strength (kg)	169	21.2	62.0	39.2 ± 8.5	
Originality	166	27	167	78.0 ± 29.7	
Cognitive fluency	166	6	40	19.1 ± 6.6	
Elaboration	166	2	60	22.4 ± 10.1	
Cognitive flexibility	166	5	31	15.6 ± 5.2	
Creativity	166	49	261	135.1 ± 43.5	
Sedentary (min/day)	141	215.6	1302.4	758.5 ± 272.1	
Ligth (min/day)	141	46.8	158.8	92.5 ± 22.0	
Moderate (min/day)	141	8.03	45.0	25.2 ± 8.3	
Vigorous (min/day	141	5.5	53.2	22.6 ± 10.8	
MVPA (min/day)	141	14.4	92.8	47.6 ± 18.1	
LVPA (min/day)	141	10.6	178.5	140.3 ± 41.1	

Note. *n* = sample; *M* = Mean; SD = Standard Deviation; BMI = Body Mass Index; MVPA = Moderate to vigorous physical activity; LVPA = Light to vigorous physical activity.

Table 2
Bivariate correlation coefficients (CI = 95%) among measures.

	Age	Size	Weight	FM%	HGS	O	FLU	ELA	FLE	CREA	SED	LIG	MOD	VIG	MVPA
Age	1														
Size	0.395**	1													
Weight	0.254**	0.669**	1												
FM%	0.34	0.191**	0.569**	1											
HGS	−0.087	−0.180*	−0.527**	−0.446**	1										
O	0.081	0.090	0.062	−0.024	−0.072	1									
FLU	0.151	0.080	0.052	−0.028	−0.026	0.758**	1								
ELA	0.087	0.146	0.113	0.095	0.015	0.209**	0.142**	1							
FLE	0.070	0.072	0.060	−0.015	0.027	0.667**	0.884**	0.108*	1						
CREA	0.094	0.127	0.084	−0.010	−0.053	0.969**	0.778**	0.420**	0.683**	1					
SED	0.241**	0.126*	0.170**	0.265**	−0.086	0.075	0.122	0.110	0.060	0.080	1				
LIG	−0.153	−0.099	0.126	0.115*	−0.135	0.118	0.022	0.037	0.052	0.110	0.098	1			
MOD	−0.049	−0.033	0.114	0.027	−0.048	0.166	0.093	0.018	0.112	0.165	0.020	0.761**	1		
VIG	−0.201*	−0.108	−0.056	−0.156	0.062	**0.189****	**0.216***	−0.031	**0.272****	**0.163****	0.028	0.494**	0.617**	1	
MVPA	−0.145	−0.060	0.007	−0.078	0.018	**0.168****	**0.202***	−0.004	**0.242****	**0.154****	0.033	0.559**	0.791**	0.960**	1

Note. FM% =% Fat mass; HGS = Hand grip strength; *O* = Originality; FLU = Fluency; ELA = Elaboration; FLE = Flexibility; CREA = Creativity; SED = Sedentary; LIG = Light physical activity; MOD = Moderate physical activity; VIG = Vigorous physical activity; MVPA = Moderate to vigorous physical activity; *$p<$ 0.05; **$p<$ 0.01.

Table 3
Multiple regression analysis for PA variables predicting creativity.

Variable	B	t	Significance
SED	0.111	1.328	0.187
LIG	−0.094	−0.906	0.367
MOD	−0.080	−0.600	0.550
VIG	0.904	2.537	**0.012**
MVPA	−0.174	−0.600	0.084
LVPA	−0.133	−0.913	0.333

Note. SED = Sedentary (min/day); LIG = Light physical activity (min/ day); MOD = Moderate physical activity (min/ day); VIG = Vigorous physical activity (min/day); MVPA = Moderate to vigorous physical activity LVPA (min/day); LVPA = Light to vigorous physical activity (min/day).

(Table 4).

Regarding the variable O, the vigorous physical activity predictor ($B = 0.680$, B SE = 0.228, β = 0.248, $t = 2.981$, CI [0.229, 1.131]) significantly accounted for 6.1% (95% CI for R2; adjusted R2 = 0.054) of variance of 0, F (1, 136) = 8.888, $p = 0.003$. At the same time, we find that the vigorous physical activity predictor ($B = 0.210$, B SE = 0.052, β = 0.210, $t = 2.503$, CI [0.027, 0.231]) significantly accounted for 4.4% (95% CI for R2; adjusted R2 = 0.037) of variance of FLU, F (1, 136) = 6.226, $p = 0.013$ (Table 4).

If we consider FLE variable, the vigorous physical activity predictor ($B = 0.121$, B SE = 0.040, β = 0.252, $t = 3.042$, CI [0.042, 0.200]) significantly accounted for 6.4% (95% CI for R2; adjusted R2 = 0.057) of variance of FLE, F (1, 136) = 9.254, $p = 0.003$ (Table 4). However, the relationship between the ELA variable and vigorous physical activity was not significant.

The present study was based on the hypothesis that there exist a positive relationship between physical activity, especially that of moderate to vigorous intensity, and the different components of creativity, so that the most physically active students will also be more creative. The results obtained show that our hypothesis is partially confirmed, since MVPA and vigorous physical activity are positively and significantly related to FLU and positively and highly significantly related to O and FLE and creativity in general. However, no relationship was found between light or moderate physical activity with any of the creativity components or with creativity in general. We can also state that ELA ability was not related to any level of intensity of physical activity. Therefore, and according to the results shown, we can also affirm that the most physically active students are also more creative.

4. Discussion

This study aimed to analyze whether there is a relationship between creative ability, intensity and amount of physical activity in 10–11 year old children. Hence, regarding the levels of physical activity and creativity, focusing our attention on the results obtained in anthropometric variables, body composition and hand grip strength, the data does not show a strong correlation with respect to the cognitive variables. However, it is important to highlight some correlations that can be remarked in this study, where in terms of physical activity and sedentary behavior it was determined that the variable SED was positively and significantly related to age and weight. Nevertheless, in relation to the components of divergent thinking, no correlations were found with sedentary behavior. In this sense, our results may eventually be justified with environmental factors (Frith et al., 2019; Leso, Dias, Ferreira, Gama & Couceiro, 2017), including the physical activity performed (e.g., quantity, intensity and typology).

As for the environmental factors that can favor the creativity of an individual, we have to take into account the social and family context and the environment where the child is inserted (Grao-Cruces et al., 2016; Sternberg et al., 2004), as well as the teaching methods (Besancon & Lubart, 2008), the school environment (Deng et al., 2016) and even the birth order (Lubart, 2003). On an embodied account of cognition, creative development happens as a result of the acting on and within an environment (Gubenko & Houssemand, 2022; Harbourne & Berger, 2019; Malinin, 2019; Shapiro & Stolz, 2019).

In this sense, one of the environmental factors that could influence the cognitive components related to creativity is the physical activity performed. However, too little work to date has explored the potential of physical activity to influence embodied creativity and very few have focused on a school context nor on a crucial age interval (10–11 years old). This is despite the fact that the literature shows a tendency to move from "cognitive exploration" to "cognitive alignment" throughout childhood, and researchers have suggested that a decline in creativity that begins in the fifth year of life may peak at eleven when they complete elementary school (Frith et al., 2019).

On the other hand, taking into account the relationship between physical activity and creative capacity, several studies are in line

Table 4
Multiple regression analysis for vigorous physical activity predicting components of divergent thinking.

Variable	B	R^2	Adj R^2	t	Significance
O	0.086	0.061	0.054	2.981	**0.003**
FLU	0.323	0.044	0.037	2.503	**0.013**
ELA	−0.080	0.006	−0.002	−0.887	0.376
FLE	0.502	0.064	0.057	3.042	**0.003**

Note. *O* = Originality (obtained score); FLU = Fluency (obtained score); ELA = Elaboration (obtained score); FLE = Flexibility (obtained score).

with some of the results obtained in our research (Frith et al., 2019; Jung et al., 2021; Kim, 2015; Lupu, 2012; Piya-amornphan et al., 2020; Roca et al., 2018), where there is a tendency for physical activities to favor and increase creativity (Latorre Román, Pantoja Vallejo & Berrios Aguayo, 2018; Lupu, 2012). However, even so, it is important to emphasize that the major part of these investigations lacks more solid foundations to better support these assumptions (Frith et al., 2019). Cutting through, some authors (e.g., Molteni et al., 2002; Ratey & Loehr, 2011) have reported that physical activity tends to lead to an improvement of synaptic plasticity, functional connectivity of cortical neuronal networks, and may also facilitate the activation of the hippocampus, which plays a key role in the creative process (Kim et al., 2011; Talukdar et al., 2017). This is in addition to an increase in neuronal activity and volume in the prefrontal regions related to cognitive processes, capable of producing novel results (Beaty et al., 2014; Colombo et al., 2015). Moreover, numerous internal and environmental factors tends to influence the creative process (Kandler et al., 2016, 2014; Simonton, 2014). These factors are joined by other conative ones related to personality (Barbot et al., 2011; Mumford & Gustafson, 1988), self-acceptance and self-control (Selby et al., 2005).

Another relevant result of our study indicate that, from selected cut-off points (Evenson et al., 2008), the sample performs a means of 92.5 $\pm$ 22.0 min per day of light physical activity, 25.2 $\pm$ 8.3 of moderate physical activity, 22.6 $\pm$ 10.8 of vigorous physical activity, and 47.6 $\pm$ 18.1 of MVPA. In this case, de Greeff, Bosker, Oosterlaan, Visscher and Hartman (2018) indicate that MVPA can cause an increase and development of the structural network of the brain, inducing the synaptic release of neurotransmitters (e.g., dopamine) (Frith & Loprinzi, 2018; Köhncke et al., 2018). Therefore, physical activity and the dopaminergic system may be related to creative capacity and play an important role in this stronghold (Frith & Loprinzi, 2018; Takeuchi et al., 2010; Zabelina, Colzato, Beeman & Hommel, 2016). In addition, it is important to emphasize here that further studies are needed to consolidate this aspect, particularly in an educational context and especially with children (Frith et al., 2019).

Otherwise, our results are not entirely enlightening with regard to creative potential and the definition of "creative person", which, according to the specialized literature, tends to be one that has novel ideas (Runco & Jaeger, 2012) and include aptitudes such as divergent thinking (Cayirdag & Acar, 2010; Leso et al., 2017). However, there is no consensus on a "universal definition of creativity," so that an answer considered "creative" in childhood (whether in a cognitive or physical behavior) may simply be spontaneous, rather than unexpected, surprising, interesting, and/or relevant (Dietrich & Kanso, 2010; Sternberg & Lubart, 1996).

On the other hand, the results showed a correlation between the dimensions of O, FLU and FLE both with vigorous physical activity and with MVPA. Likewise, both intensities of physical activity are positively and significantly related to overall creativity. These data emerge, potentially, as the most relevant of this study. It seems possible to state that physical activity of a certain intensity (vigorous and MVPA) may be the cause of an increase and development of the structural network of the brain (de Greeff et al., 2018), due to the increased release of dopamine, an important neurotransmitter related to motor activity, cognitive control, motivation and reward, mood, attention, inhibition, and learning (Frith & Loprinzi, 2018; Köhncke et al., 2018).

Therefore, physical activity and the dopaminergic system could be related to creative ability (Frith & Loprinzi, 2018; Takeuchi et al., 2010; Zabelina et al., 2016), being this affirmation in harmony with the concept of executive function, associated with the frontal lobe, and which controls the basic and underlying cognitive functions to develop a goal-directed behavior (Etnier & Chang, 2009; Merchán-Naranjo et al., 2016). Note that basic cognitive skills are processes learned through repetition and practice (Etnier & Chang, 2009). In them we can also include metacognition, cognitive fluency and working memory (Diamond, 2013; Kofler et al., 2019), something that can influence the information processing in cognitive function (e.g., central nervous system) and in the creative act itself (Frith & Dolan, 1996), as well as in executive control (Frith & Loprinzi, 2018; Khalil et al., 2019).

In this regard, the specialized literature (e.g., Lustenberger, Boyle, Foulser, Mellin & Fröhlich, 2015; Tachibana, Noah, Ono, Taguchi & Ueda, 2019) shows that individuals with optimal levels of creativity may have the ability to engage in goal-consistent behaviors, while inhibiting goal-inconsistent behaviors, whereby modulation of brain activity in the prefrontal cortex contributes to specific aspects of the production of creative behaviors. Thus, creative cognition represents an important feature in a variety of everyday life contexts and specific domains (Oppici et al., 2020).

Finally, despite the lack of consensus in establishing a universal definition of creativity, it seems proven that it is a cognitive ability that requires higher-level components and that is located in the prefrontal cortex (Frith & Dolan, 1996), being supported by the executive control network (Frith & Loprinzi, 2018), so knowing its nature, the factors on which it depends and how to develop it are questions of interest in many fields of the social sciences. Going along with Weisberg (2015), it is necessary to measure and study creativity as an intellectual function, thus enervating the importance of creativity in education and bringing creativity closer to the world of psychology, but also to direct it to other fields (artistic, musical, among others) (Almeida et al., 2008).

In sum, the creativity that we obtained in the results of this study refers to divergent thinking, which is considered as the creative act of generating multiple solutions from a single stimulus (Berkowitz, Reynolds, Vannest & Fletcher-Janzen, 2014), and is in turn a tool to predict creative potential (Allen & Tomas, 2011; Runco et al., 2008). It also has implications for the originality of thinking, where a child can find and obtain as many solutions as possible in order to solve a given problem (Ferrándiz García et al., 2017; Humble et al., 2018; Krumm et al., 2016). Hence, creativity can be considered as a broad construct that encompasses the ability to break traditional or obvious patterns of thinking, adopt new or higher-order rules, and generate new solutions to specific problems (Dietrich & Kanso, 2010; Sawyer, 2011). So, understanding which mental and environmental factors may promote or inhibit creative thinking processes is critical to setting up models that adequately address creative cognition across domains (Matheson & Kenett, 2020).

5. Conclusion

Regarding age, anthropometric variables, body composition and hand grip strength, it is concluded that no correlations were found with cognitive variables. However, hand grip strength was significantly and negatively related to size and% fat mass, but it was not related to any of the components of creative thinking.

On the other hand, regarding physical activity and sedentary behavior, the variable SED was positively and significantly related to age, size, weight and% fat mass. Also, light physical activity was positively and significantly related to% fat mass and vigorous physical activity was negatively and significantly related to age. In relation to the components of divergent thinking, sedentary behavior was not significantly related to any of them.

With respect to the different intensities of physical activity, there is no correlation with ELA capacity. However, vigorous physical activity is positively and significantly related to FLU, and positively and highly significantly related to O, FLE and creativity in general. Moreover, the relationship between the ELA variable and vigorous physical activity was not significant.

Given the above, it is concluded that the "key to creativity" may depend on a combination of cognitive, social and family factors, among others. Although there is a tendency for a positive correlation between physical activity and creative ability, more studies are needed to better consolidate these assumptions.

Future studies on this topic may investigate other factors related to self-acceptance, dominance and self-confidence and their influence on physical activity and creative ability.

5.1. Study limitations

Although the use of accelerometers minimized information bias, provided an objective measure of children's sedentary lifestyles and physical activity at different intensities, and increased the validity of the external results, it should be noted that these devices underestimate the intensity of certain physical activities that, although intense, do not necessarily involve movement, displacements or acceleration (soy they are not recorded).

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CRediT authorship contribution statement

Ramón Romance: Conceptualization, Methodology, Data curation, Funding acquisition, Project administration, Supervision. **Adriana Nielsen-Rodríguez:** Methodology, Formal analysis, Investigation, Writing – original draft. **Rui Sousa Mendes:** Funding acquisition, Project administration, Validation, Supervision, Writing – review & editing. **Juan Carlos Dobado-Castañeda:** Data curation, Investigation, Software, Writing – review & editing. **Gonçalo Dias:** Formal analysis, Investigation, Validation, Writing – original draft.

Declaration of Competing Interest

The authors have no relevant financial or non-financial interests to disclose. The authors have no conflicts of interest to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Data availability

Data will be made available on request.

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