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ORIGINAL RESEARCH

Prediction of Arithmetic Abilities of Children Who Practice Sports: The Use of the Gamma Model

Authors' Contribution:
A – Study design;
B – Data collection;
C – Statistical analysis;
D – Data interpretation;
E – Manuscript preparation;
F – Literature search;
G – Funds collection

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Abstract

Background and Aim of Study: *The physical performance that children exhibit when engaging in sports or any form of physical activity will depend not only on their physical abilities but also on their psychological and cognitive attributes.*
The aim of the study: to analyze whether symptoms of anxiety, lie, attention, and age are predictors of arithmetic abilities in children practicing sports.

Material and Methods: *The study sample consisted of 108 children with an average age of 12.12 (±2.18) who practice various sports, with greater emphasis on futsal and soccer. The study protocol consisted of a sociodemographic questionnaire, the Revised Children's Manifest Anxiety Scale, the d2 Test of Attention, and the Arithmetic subtest of the Wechsler Intelligence Scale for Children.*

Results: *The results showed that through the adjusted model, we identify four significant explanatory variables that are predictors of arithmetic abilities, namely anxiety symptoms (β=-0.009, p=0.009); and the attention sub-factors: processed characters (β=0.002, p=3.44e-14), default errors (β=-0.005, p=0.000), errors by marking irrelevant characters (β=-0.016, p=0.003).*

Conclusions: *The presence of anxiety symptoms and attentional cognitive abilities play a significant role in predicting the arithmetic aptitudes of young individuals. These variables should be taken into consideration within training programs for young athletes, as they hold relevance for sports engagement.*

Keywords: *sports participants, anxiety, lie, attention, age, arithmetic skills*

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Introduction

Physical activity and sports hold a pivotal role in the promotion of health and overall well-being. The engagement of young individuals in physical activities and sports has been correlated with favorable impacts on their mental health, encompassing emotional states, behavioral patterns, and cognitive proficiencies (Hosker et al., 2019). The cultivation of cognitive capacities, particularly arithmetic abilities, equips children and adolescents with enhanced precision in numerical comprehension, mathematical operations, point enumeration, and improved numerical estimations, among other competencies (Landerl, 2013; Reeve et al., 2012). These proficiencies are notably nurtured through participation in games (Butterworth, 2005). The refinement of such abilities necessitates the establishment of neural connections, exemplified by linkages between visual and verbal networks, as well as visual and spatial networks (Rapin, 2016), both of which hold equal significance in the context of sports performance (Tamorri, 2004). Moreover, a discernible correlation has been substantiated between arithmetic skills and self-reported levels of physical activity, aerobic fitness, and motor prowess (Syväoja et al., 2021). Notably, motor skills have been identified as integral to fundamental numerical abilities, encompassing aspects such as symbolic representation on the number line (number identification) and nonsymbolic representation (object identification) (Gashaj et al., 2019a). The predictive linkage between fine motor skills and arithmetic competencies is also highlighted in a study conducted by Michel et al. (2020) involving 173 children. The utilization of gestures or manual manipulations has been shown to confer benefits in the accuracy and swiftness of item counting (Carlson et al., 2007). The presence of proficient fine motor skills additionally emerges as a predictor for mathematical prowess among children aged 7 to 8 years, as evidenced by Gashaj et al. (2019b). In light of these insights, it becomes apparent that sports training and the augmentation of motor capabilities exert tangible effects upon the arithmetic aptitudes of children who are engaged in sports activities. Moreover, in accordance with the investigation conducted by Wu et al. (2017), cognitive faculties encompassing working memory and attention, alongside affective constituents such as mathematical anxiety, emerge as pivotal contributors to mathematical performance across both verbal and non-verbal tasks. Nevertheless, the presence of mathematical anxiety has been shown to impede the cognitive processes essential to proficient task execution within this domain (Orbach et al., 2020). Mathematical anxiety constitutes an adverse emotional response characterized by feelings of unease and apprehension that students experience when confronted with mathematical exercises (Hill et al., 2016), and this phenomenon can exert a detrimental influence on their mathematical comprehension and problem-solving skills (Vukovic et al., 2013). Such anxiety can instigate intrusive negative thoughts and engender a perception of environmental stimuli as threatening. Consequently, instances of math anxiety within children can elicit avoidance behaviors when confronted with arithmetic challenges (Orbach et al., 2020). Consequently, it is hypothesized that the presence of anxiety may disrupt the arithmetic proficiencies of the participants under examination. However, an alternative perspective posited by Wu et al. (2017) contends that when mathematical anxiety prevails, there might be an elevation in children's levels of vigilance, potentially serving as a mitigating factor against the adverse impact of attentional deficits on mathematical performance. Steele et al. (2012) study, analyzing the developmental trajectory of children's attentional capacities, identified sustained-selective attention as a predictive indicator of fundamental mathematical abilities over a one-year observation period. Evidently, tasks involving counting necessitate the engagement of serial attentional processes. In these contexts, discrepancies in attentional proficiency may contribute to disparities in children's performance concerning mathematical problem-solving (Wu et al., 2017). The mechanism of attention entails focusing on stimuli of significance, thereby sieving a substantial portion of sensory input and directing cognitive processing toward selected components (Broadbrent, 1958; Deutsch & Deutsch, 1963). Within the realm of sports, attention assumes a pivotal function for athletes in identifying, selecting, or quantifying pertinent stimuli during both training sessions and competitive events (Carrascosa, 2003). This perspective prompts us to contemplate the possibility of attention serving as a predictive determinant of arithmetic proficiencies among children engaged in sports. Nevertheless, instances may arise wherein children, when grappling with task challenges, resort to deception. This utilization of deceit can manifest as a coping mechanism for evading tasks, concealing uncertainties, and masking weaknesses (Matias et al., 2015). Children frequently deploy falsehoods as a means of navigating their recreational pursuits. In the sporting context, the dissemination of false information can also be construed as an intentional strategic maneuver that disadvantages adversaries and strategically shapes opponents' behavior (Sailors et al., 2017). According to Ommundsen et al. (2003), children undergoing training to enhance soccer performance often exhibit heightened tendencies towards amoral conduct compared to their peers demonstrating elevated sociomoral maturity and adherence to fair-play principles. The conceptual framework advanced by Bransford and Stein (1993) frames lying as a form of decision-making employed when resolving problems risks compromising achievement objectives. As children mature, their cognitive capacities for fabricating falsehoods improve (Evans & Lee, 2011), thereby signifying that older children tend to wield lies more adeptly (Maggioni & Rossignoli, 2020). In this vein, it is posited that age and the engagement in deceit could potentially exert influence over the arithmetic abilities of children. Nonetheless, the intricacies of these abilities continue to command substantial scholarly attention. Scientific inquiry has delved into the associations between arithmetic skills and various cognitive constructs, including working memory, executive functions (Orbach et al., 2020; Swanson & Beebe-Frankenberger, 2004), interactivity, mathematical anxiety (Vallée-Tourangeau, 2013), performance (Salminen et al., 2018), and even finger-counting practices (Barrocas et al., 2020; Crollen & Noël, 2015). While Becker et al. (2018) have demonstrated a correlation between engagement in team sports and enhanced mathematical problem-solving abilities, studies investigating the interplay of attention, anxiety, deception, and age in the mathematical capacities of children and adolescents active in sports are conspicuously scarce.

The aim of the study. To examine how symptoms of anxiety, lying, attention, and age are predictors of mathematical abilities in children who practice sports.

Materials and Methods

Participants

This observational, cross-sectional study, based on a non-probabilistic sample, considered 108 Portuguese participants with a mean age of 12.12 years (±2.18), ranging from a minimum of 8 years to a maximum of 16 years. Most participants are male 66.7% and have completed the 3rd cycle of education (9 years of education) (43.5%). The most popular sports in the sample are futsal (37.0%), football (25.0%), taekwondo (17.6%), rhythmic gymnastics (7.4%), and tennis (7.4%). Participants have been practicing sports, on average, for 54.85 (±28.68) months and the average weekly training time is 3.97 hours (±2.6). As inclusion criteria, young athletes from sports clubs for at least one year were considered. Participation in the study was only accepted after signing the informed consent of the young person and their legal representative. They were informed that their participation was completely voluntary and harmless. Young people with developmental disorders or other physical and mental conditions that did not allow them to respond to the study protocol were not considered in this study. All ethical and deontological duties inherent to the investigation were considered.

Measures

For the present investigation, a sociodemographic questionnaire was used to collect information about the participants (e.g., age, sex, time of the sport, etc.). The Revised Children's Manifest Anxiety Scale (CMAS-R; Portuguese version by Dias & Gonçalves, 1999) was applied. This scale evaluated the global anxiety index and the global lie index. Anxiety was assessed using 28 items ranging from a minimum of 0 to a maximum of 28 points. The global lie index was evaluated using 9 items, varying between a minimum of 0 and a maximum of 9 points. High values represent a high level of lying on the part of the participant. According to the authors, this instrument has good reliability as represented by a Cronbach's alpha of 0.80 (Dias & Gonçalves, 1999). The d2 Test of Attention was used to measure children's selective attention and concentration, through 14 lines, each with 47 stimuli (of the letters p and d accompanied by either one or two quotation marks or comma) from which the participant must identify the letter "d" with two upper quotation marks (Brickenkamp & Zillmer, 2010). Through this instrument, it was possible to calculate the Total Processed Characters, PC (that is the number of stimuli indicated, taking into account the participant's speed, productivity, or motivation); the Total Hits, TH (that is the effectiveness in performing the task); the Total Effectiveness, TE (which measured the level of attentional control and the relationship between speed and accuracy throughout the task); the Concentration Index, CI (indicating the level of concentration in the task); the Variability Index, VI (which revealed whether the task was performed consistently or in a variable way); and Percentage of Errors, E% (which showed the accuracy and quality of performance). The Portuguese version of the instrument revealed a Cronbach's Alpha greater than 0.90 (Brickenkamp & Zillmer, 2010). Finally, the Arithmetic subtest of the Wechsler Intelligence Scale for Children (Portuguese version by Simões, 2002) was applied to assess the participants' calculus, logical-mathematical reasoning, and problem-solving skills through 24 items. The score varies between a minimum of 0 and a maximum of 24 points, with high scores reflecting good arithmetic and reasoning skills (Wechsler, 1991/2003; Simões, 2002). The Portuguese version of this subtest showed good internal consistency with a Cronbach's Alpha of 0.84 (Simões, 2002).

Procedure

First, the directors of several sports clubs in the Lisbon region were contacted. The study objectives were presented to the directors and permission was sought to contact the athletes' legal representatives. After getting approval, the athletes' legal representatives were contacted. They were informed about the study's objectives, the confidentiality of the information collected, the voluntary nature of the investigation, and the ethical and deontological duties of the investigators. They were then asked to sign their informed consent. After authorization by the legal representatives, the athletes who were willing to participate were contacted. After this period, sessions were scheduled with the participants who were individually assessed. The protocol application site was a room belonging to the sports clubs that collaborated in the investigation. The researchers respected all ethical and deontological duties and there was no risk of any kind to the participants.

Data Analysis

For the present investigation, the statistical software R, R-Studio, was used for data analysis. Descriptive statistics were used to characterize the sample, specifically the analysis of means and standard deviations for quantitative variables and the analysis of frequencies and percentages for nominal variables. A Gamma Regression Model was used to study the response variable, using a logarithmic link function. The step function of R was also used to automatically select the covariates that should be included in the gamma model. The significance level assumed in this study was p-value <0.05.

Results

Prediction of Arithmetic Skills

The following table (Table 1) shows the coefficients of the explanatory variables of the athletes' arithmetic skills.

At the usual significance levels (5%), this model reveals that there is a significant covariate, namely anxiety symptoms. Residual deviations range from -0.43 to 0.40 and the calculated value of the residual deviation is 2.766 for 100 degrees of freedom. The measure of the quality of this adjustment given by the Akaike Information Criterion (AIC) is 501.05.

Then, the covariates that should be included in the gamma model were automatically selected and a new adjustment value of the resulting model was performed. According to the new adjusted model (Table 2), the new coefficients and covariates of the model are identified.

Table 1

Variable Coefficients: Age, Anxiety Symptoms, Lie, Attention: Processed Characters, Attention: Hits, Attention: Default Errors, Attention: Errors by Marking Irrelevant Characters

Coefficients	Estimated value	SE	*t*-value	*p*-value
Intercept	2.139	0.122	17.423	$<2e^{-}16$***
Age	0.007	0.009	0.77	0.44
Anxiety symptoms	-0.007	0.004	-2.06	0.04*
Lie	0.002	0.007	0.36	0.72
Attention, PC	0.001	0.002	0.45	0.66
Attention, Hits	0.002	0.006	0.25	0.80
Attention, DE	-0.003	0.006	-0.56	0.58
Attention, EMIC	-0.009	0.005	-1.91	0.06

Note. SE – standard error; *p*-value: *0.05; **0.01; ***0.001; PC – processed characters; DE – default errors; EMIC – errors by marking irrelevant characters.

Table 2

Variable Coefficients: Anxiety Symptoms, Attention: Processed Characters, Attention: Default Errors, Attention: Errors by Marking Irrelevant Characters

Coefficients	Estimated value	SE	*t*-value	*p*-value
Intercept	2.222	0.082	27.161	$<2e^{-}16$***
Anxiety symptoms	-0.009	0.004	-2.48	0.015*
Attention, PC	0.002	0.000	8.86	$2.51e^{-}14$***
Attention, DE	-0.005	0.001	-4.00	0.000***
Attention, EMIC	-0.009	0.005	-1.92	0.057

Note. SE – standard error; *p*-value: *0.05; **0.01; ***0.001; PC – processed characters; DE – default errors; EMIC – errors by marking irrelevant characters.

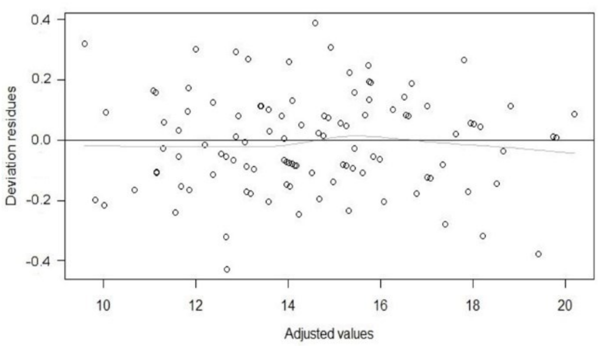
During the adjustment, three covariates were eliminated from the model, namely, age, lying, and the total number of hits of the attention task.

On the other hand, there were more significant covariates, a total of three new significant covariates, for the usual significance levels (5%). These variables are anxiety symptoms, the characters processed in the attention task, and the omission errors in the attention task. Residual deviations range from -0.43 to 0.39, with a residual deviation value of 2.740 with 103 degrees of freedom. The AIC value is 496.0. The *p*-value calculation to verify the suitability of this model shows a *p*-value=1. Considering the value of 1 obtained, it is accepted that this model is adequate and proves to be better than the previous model.

Through the analysis of the residuals of the adjusted model (Figure 1), it is verified that the residuals are distributed around 0, with an amplitude that seems constant for the different adjusted values, without verifying any trend. This also indicates that this model fits this dataset well.

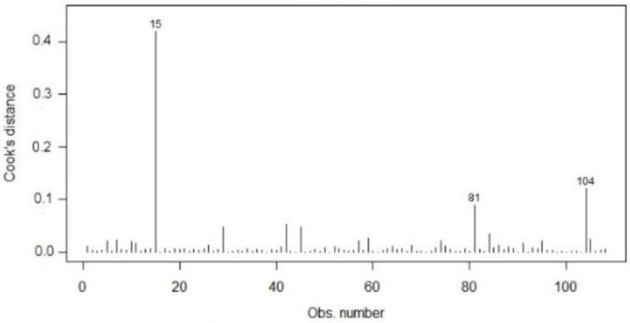
Figure 1

Representation of the Adjusted Model Residuals



Through the calculation of Cook's distances (Figure 2), the observations effectively influencing the model were verified. Thus, 3 effectively influential observations were identified, namely observations 15, 81, and 104, that is, a slight modification or exclusion of these observations from the model could cause significant changes in the estimates of the model parameters.

Figure 2
Calculation Results for Cook's Distances



Then, these three observations were removed from the model and the gamma model was adjusted again (Table 3). The sample now has 105 participants.

In this model, it appears that there are two significant covariates, namely, anxiety symptoms and errors by marking irrelevant characters.

Residual deviations range from -0.42871 to 0.39180. The AIC value is 480.56 and the residual deviation value is 2.5263 for 97 degrees of freedom. The suitability analysis of this model shows a p-value=1.

According to the value of 1 obtained, the hypothesis that this regression model is adequate is not rejected.

Then, a new value of the adjustment of the model was carried out, from which the covariates to be included in the gamma model were automatically selected.

The set of covariates and their coefficients obtained with the newly adjusted model are shown in Table 4.

Table 3
Variable Coefficients: Age, Anxiety Symptoms, Lie, Attention: Processed Characters, Attention: Hits, Attention: Default Errors, Attention: Errors by Marking Irrelevant Characters for Adjusted Sample

Coefficients	Estimated value	SE	*t*-value	*p*-value
Intercept	2.179	0.122	17.747	<2e^{-}16***
Age	0.006	0.009	0.72	0.48
Anxiety symptoms	-0.008	0.004	-2.26	0.03*
Lie	0.002	0.007	0.31	0.76
Attention, PC	0.001	0.002	0.47	0.64
Attention, Hits	0.001	0.007	0.16	0.87
Attention, DE	-0.003	0.006	-0.56	0.58
Attention, EMIC	-0.016	0.005	-3.06	0.003**

Note. SE – standard error; *p*-value: *0.05; **0.01; ***0.001; PC – processed characters; DE – default errors; EMIC – errors by marking irrelevant characters.

Table 4
Variable Coefficients: Anxiety Symptoms, Attention: Processed Characters, Attention: Default Errors, Attention: Errors by Marking Irrelevant Characters for Adjusted Sample

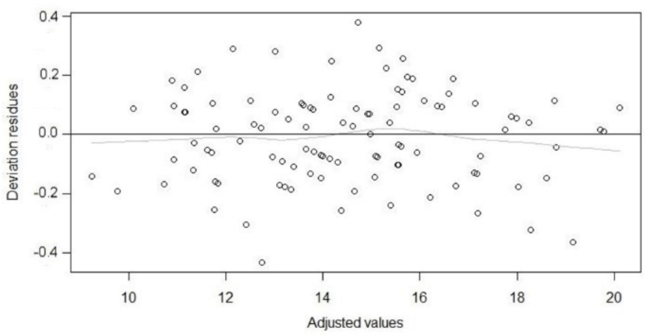
Coefficients	Estimated value	SE	*t*-value	*p*-value
Intercept	2.25	0.081	27.824	<2e^{-}16***
Anxiety symptoms	-0.009	0.003	-2.664	0.009**
Attention, PC	0.002	0.000	8.84	3.44e^{-}14***
Attention, DE	-0.005	0.001	-3.52	0.000***
Attention, EMIC	-0.016	0.005	-3.088	0.003**

Note. SE – standard error; *p*-value: *0.05; **0.01; ***0.001; PC – processed characters; DE – default errors; EMIC – errors by marking irrelevant characters.

In this new adjustment, three covariates were eliminated, namely, age, lying, and the total number of hits of the attention task. With this new adjustment, there were now four significant covariates: anxiety symptoms, characters processed in the attention task, errors by omission, and errors by marking irrelevant characters in the attention task. Residual deviations range from -0.43140 to 0.37738. The AIC value is 475.34 and the residual deviation value is 2.5450 with 100 degrees of freedom. The value of p-value=1 and, for this reason, it is accepted that this model is adequate. The analysis of the model's residuals (Figure 3) shows that the residuals are distributed around 0, which indicates that this model fits well with this data set.

Comparing this model with the previously adjusted model, this model turns out to be better than the previous one for this dataset.

Figure 3
Representation of the Residuals of the New Adjusted Model



Discussion

The primary aim of this investigation was to ascertain whether indicators of anxiety symptoms, deceptive behavior, attentional capacity, and age could serve as predictive factors for arithmetic proficiency among children engaged in sporting activities.

Our findings demonstrated that manifestations of anxiety symptoms, processing of characters during the attentional task, instances of omission errors, and errors associated with marking irrelevant characters in the attention assessment all function as predictors for arithmetic aptitude in the child and adolescent demographic.

Drawing from the research conducted by Wu et al. (2017), it was established that in eight-year-old children, the presence of math-related anxiety exerted a noteworthy and consistent indirect impact on nonverbal performance in numerical operations and mathematical reasoning. Furthermore, in tasks of heightened complexity, mathematical anxiety exhibited both direct and indirect effects (via working memory) on mathematical reasoning abilities. Conversely, it was posited that the adoption of cognitive reappraisal strategies for mathematical tasks, resulting in diminished negative affect and amygdala responses to anxiety-inducing situations, could lead to a reduction in anxiety levels, thereby potentially enhancing mathematical performance (Pizzie et al., 2020). In accordance with Wu et al. (2017) findings, instances where children experience anxiety pertaining to arithmetic tasks may paradoxically lead to heightened attentional investment in the tasks, thereby substantiating the notion that anxiety's presence may not invariably yield detrimental outcomes. However, it should be noted that the presence of math-related anxiety may impede the exclusion of distracting environmental stimuli from one's focus, irrespective of the mathematical content involved (Hopko et al., 2002). This phenomenon, as elucidated by our observations, could contribute to an increased frequency of errors on the part of participants in the tasks, specifically encompassing default errors and errors arising from the misidentification of irrelevant characters during the attentional assessment. Instances of compromised focused attention, difficulties in the effective utilization of well-practiced information (e.g., basic addition or multiplication facts), or challenges in the ability to deploy and switch between diverse mathematical processes for problem-solving, collectively illuminate the adverse influence of attentional limitations on arithmetic competencies (Wu et al., 2017). Regarding the characters processed within the attention task, it has been established that these also hold predictive value for the participants' arithmetic proficiencies. A study conducted by Anobile et al. (2013) involving a cohort of 68 children aged between 8 and 11 years revealed that attentional and perceptual competencies pertaining to numerical concepts emerged as predictive indicators for the participants' mathematical scores. Even subsequent to controlling for the influence of other pertinent variables, these researchers noted that attentional faculties exhibited a sustained association with mathematical aptitude and the discernment of numerical quantities. Wong and Liu (2020) similarly affirmed that goal-directed visual attention correlated with children's arithmetic capabilities, with this connection being mediated by the subjects' enumeration proficiencies. Furthermore, our findings indicate that deceitful behavior and age do not bear significant relevance as predictors of arithmetic abilities. Costa & Pinho (2010) did not establish a notable correlation between dishonesty and arithmetic performance. However, Maggioni & Rossignoli (2020) did discern such a relationship. As children undergo cognitive maturation, they acquire the capacity to adopt inaccurate behaviors and engage in deception for competitive advantage, as delineated by Ding et al. (2018). In regard to age, despite Aragón et al. (2018) contention that arithmetic skills tend to advance in tandem with educational progression and age, such a sociodemographic parameter did not manifest as a pertinent predictor variable for arithmetic performance in our analyzed sample. While a certain nexus between subjects' age and their arithmetic aptitude might be apparent (Nogues & Duro, 2016), other factors like the intensity of physical demands inherent to training regimens could exert a more salient influence upon cognitive proficiencies, particularly within the realm of arithmetic, as asserted by Coe et al. (2006). The implications of this study extend to sports clubs and similar organizations, offering insights for designing interventions aimed at bolstering cognitive capacities, particularly attentional and arithmetic proficiencies, while concurrently fostering emotional regulation among athletes, given their pronounced impact on athletic performance. However, it should be acknowledged that this study did not account for the potential effects stemming from other cognitive variables, such as working memory, which could impinge upon attentional capabilities (Orbach et al., 2020), consequently influencing the resolution of arithmetic tasks (Michel et al., 2020). Additionally, the potential influence of negative affect on task performance among participants remained unexamined (Storbeck & Clore, 2007). Subsequent research endeavors should endeavor to delineate more precise participant characteristics concerning this task domain, thereby enhancing control over potentially influential variables within analytical models, as well as probing the ramifications of psychological symptoms on the mathematical proficiencies of youth engaged in sports.

Conclusions

This study allows for the conclusion that the presence of anxiety and attentional characteristics such as processing of characters during the attentional task, instances of omission errors and errors by marking irrelevant characters hold predictive power over the arithmetic abilities of the youth.

This type of variables is important for the sports performance of young individuals and should be integrated into training and development programs for athletes to help them maximize their athletic performance.

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Ethical Approval

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