PEDIATRIC HIGHLIGHT

Correlates of changes in BMI of children from the Azores islands

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Objective: To model changes in body mass index (BMI), including its stability, and to investigate the association between physical activity, 1-mile run/walk and levels of gross motor coordination and BMI during 5 consecutive years.
Design: A longitudinal study of children 6 years of age at baseline followed at annual intervals over 5 years.
Subjects: A total of 285 children (143 boys and 142 girls) were enrolled in grade 1 (age 6 years) and followed through grade 5 (age 10 years).
Measurements: BMI was recorded and physical activity was assessed by questionnaire, aerobic fitness was evaluated with the 1-mile run/walk and gross motor coordination was measured with the KTK test battery (Körperkoordination test für Kinder). Multilevel modelling techniques were for the primary analysis.
Results: Changes in BMI showed similar curvilinear trends in boys and girls, with ample inter-individual crossing trajectories that is, low tracking. Longitudinal changes in physical activity (PA) and aerobic fitness were not significantly associated with BMI-changes during the 5 years. Children who were more proficient in their motor coordination showed lower values of BMI during the 5 years.
Conclusions: BMI trajectories of both boys and girls show low tracking of BMI-values. Considerable inter-individual variation exists both in baseline BMI-values and changes (velocity and acceleration) over time. PA and fitness were not associated with BMI-changes, but gross motor function was negatively associated with BMI-changes. No gender-specific associations were found. If confirmed in other populations these observations could be translated in the promotion of physical activities that improve gross motor function in children aged 6–10 years. This seems to be of major importance for the physical education curriculum of primary school children.
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Introduction

Childhood overweight and obesity have been increasing for the past two decades in developed nations and, to some extent, in other parts of the world.[1,2] A recent cross-sectional study by Padez *et al.*[3] shows a high prevalence of overweight and obesity (31.5%) in Portuguese children, aged 7–9 years old, similar to other Mediterranean countries such as Spain with 30%[4] and Greece with 31%.[5] These data call for urgent national interventions with diversified programs to control

childhood obesity and to prevent further declines in child health. Increases in overweight and obesity in children are associated with physical health problems including poorer pulmonary function,[6] hyperinsulinemia,[7] glucose intolerance,[8] diabetes,[9] hypertension[10] and a wide range of less common pathological conditions.[11]

In a representative sample of US kindergarten children aged 5–11 years, Danner[12] found a significant positive longitudinal association between body mass index (BMI) acceleration and hours of television viewing. Utter *et al.*[13] demonstrated that in New Zealand children aged 5–14 years old, physical activity (PA) was inversely associated with BMI. Kim *et al.*[14] have also shown that passing rates in physical fitness tests were lower among students (5–13 years) with higher BMI. Graf *et al.*[15] in their cross-sectional study showed that overweight and obesity were associated with poorer body gross motor coordination and endurance performance

1488

in primary school children. There is also the evidence that a decrease in physical fitness over time is associated with declines in PA and consequently an increase in overweight.[16]

In summary, it appears that PA and physical fitness are linked to BMI; this complex of factors (lower levels of fitness and PA), may contribute to the recent rise in the prevalence of obesity among children. To our knowledge, no study has addressed the issue of correlates of BMI changes in children followed longitudinally from 6–10 years of age, using PA, gross motor coordination and aerobic fitness as time-varying predictors. Therefore, the aims of this study were to: (1) model changes in BMI over a period of 5 years in children followed longitudinally from 6 to 10 years; (2) study the stability of inter-individual differences in intra-individual changes in BMI; (3) verify the presence of gender differences; (4) describe the 'effects' of two time varying covariates, PA and 1-mile run/walk on changes in BMI trajectories, that were also measured longitudinally over the 5-year period; and (5) determine if different levels of gross motor coordination predict changes in BMI.

Materials and methods

Sample
The sample was selected from a mixed longitudinal study conducted in the Azores islands. This study was designed to evaluate growth, PA, gross motor coordination, body composition, physical fitness and sports motivation of children and adolescents from 6 to 19 years of age.[17] A total of 1000–1200 subjects divided in four cohorts of 250–300 subjects each were sampled and followed for 4–5 consecutive years. The first cohort was followed from 6 to 10 years, the second from 10 to 13 years, the third from 13 to 16 and the fourth from 16 to 19 years. Subjects came from four main islands (Faial, Pico, São Miguel and Terceira) which represent 99% of the total population of the nine islands. The present sample considers only 285 children from the first cohort: 142 girls and 143 boys that were followed consecutively from 6 to 10 years (primary school years). To avoid seasonal variations, all measurements were taken in the fall during a period of 2 months (September–October).

Anthropometric measures
Height was measured with a Siber Hegner anthropometer and weight was measured with a Secca scale, using procedures outlined by Lohman *et al.*[18] BMI was calculated using the usual formula (weight (kg)/height (m)^2).

PA
Children's PA was assessed by direct interview (one-to-one) with the Godin and Shephard[19] questionnaire. It quantifies the number of times per week that the children spent in different PAs, for periods equal or greater than 15 min. PA

events were considered in three different categories: mild (3 METs), moderate (5 METs) and strenuous (9 METs). A total score (METs/15 min week^{-1}) was derived by multiplying the frequency of each category by the MET value, and those products were summed.

Gross motor coordination
Gross motor coordination was assessed with the KTK test battery (Korperkoordinationstest fur Kinder), which uses a factor analysis approach. The battery has proven valid for children between 5 and 14 years of age[20] and showed good concurrent validity in the movement assessment battery for children.[21] This battery is often used in motor development research with normal and special children from Portugal[22] and Brazil.[23] The battery consists of four items that measure (a) balance capacity during backward walking on three different width balance beams (3 cm, 4.5 cm and 6 cm); (b) one-leg obstacle surmounting; (c) side jump; and (d) side locomotion and object replacement. An overall measurement of gross motor coordination is obtained by the sum of the scores obtained in the four tests adjusted for age and sex.

Aerobic fitness
The Fitnessgram 1-mile run/walk test[24] was used to assess the maximum functional capacity and the cardiorespiratory fitness levels of the children.

Data analysis
Descriptive statistics were computed in SPSS 15.0. Tracking of BMI was estimated using Foulkes and Davies[25] γ statistic. These authors suggest that perfect tracking occurs when a group of individual growth profiles do not intersect, that is, when relative rank within the response distribution is maintained over time. On the contrary, no tracking occurs if $\gamma < \frac{1}{2}$. LDA software[26] was used in these computations. Repeated measures analysis of variance was used to test for systematic changes in all variables within each gender.

Changes in BMI and its correlates (fixed and time-varying) were modelled in HLM 6.0 software within the framework of a multilevel approach, using maximum likelihood estimation procedures. BMI values were centred such that the time scale started at the beginning of the study. A series of hierarchical nested models were fitted, and the Deviance statistic was used as a measure of global fit. The Deviance statistic cannot be interpreted directly as it is a function of sample size and fit of the model. When models are nested, the differences of the Deviances follow a χ^2 distribution with degrees of freedom determined by the difference in number of estimated parameters. We started with a model that best describes BMI changes over the 5-year period (Model 1). Then we introduced the effects of the two time-varying covariates (1-mile run/walk and gross motor coordination),

which is our Model 2. Finally, in Model 3 we added gender as a covariate.

Reliability

Data quality control was assessed by means of a retesting a random sample of 160 from children aged 6–10 years of both genders from the four islands in all procedures of the study. Intraclass correlation coefficient (R) was used to estimate relative reliability, whose values were as follows: height, $R = 0.99$; weight, $R = 0.99$; 1-mile run/walk, $R = 0.72$; balancing backwards, $R = 0.79$; one-legged obstacle jumping, $R = 0.75$; jumping from side to side, $R = 0.87$; sideway movements, $R = 0.83$; and PA, $R = 0.75$.

Results

Table 1 presents main descriptive statistics (means ± s.d.) of BMI, 1-mile run/walk, PA and KTK. Boys and girls show increases in BMI means with advancing age. Starting from 7 years onwards, boys and girls tend to show better ($P < 0.05$) running performance, that is, better aerobic fitness. A significant ($P < 0.05$) continuous decline of PA was evident in girls, but not in boys in who the mean PA-values show a wave like pattern. Girls gross motor coordination increases until 9 years of age and then declines. Contrary to girls, boys tend to present a rather stable mean behavior ($P < 0.05$) in motor coordination performance.

Stability of inter-individual differences in BMI intraindividual changes over time showed very low values. In boys $\gamma = 0.51$ (95% confidence interval = 0.47–0.55), and in girls $\gamma = 0.52$ (95% confidence interval = 0.47–0.556), indicating very low tracking of BMI during the 5-year period. This is clearly seen in Figure 1 using a small set (random sample of 10% of all subjects disregarding their gender) of fitted BMI growth curves with ample crossing in all subjects.

Table 2 shows the results from Model 1. The mean BMI trajectory was estimated to start at 17.238, to slope upward at a rate of 0.031 BMI units per year, and accelerate this growth by 0.107 BMI units of time squared. The correlation between the intercept and the growth rate slope was 0.54, indicating that those children who started with higher BMIs in the first evaluation had steeper BMI slope trajectories. Random effects show that significant inter-individual differences were noted at baseline and velocity of changes in BMI.

In Model 2 (Table 3) PA, 1-mile run/walk and KTK were added as time-varying covariates, to determinate if, over time, these characteristics relate significantly to BMI-trajectories between 6 and 10 years of age. This model presents a better fit when contrasted to Model 1 ($\chi^2(3) = 840.28$, $P < 0.001$). However, PA and aerobic fitness did not show any significant association with BMI trajectories over the 5-year period. Increasing trends in BMI are negatively associated with changes in gross motor coordination. It
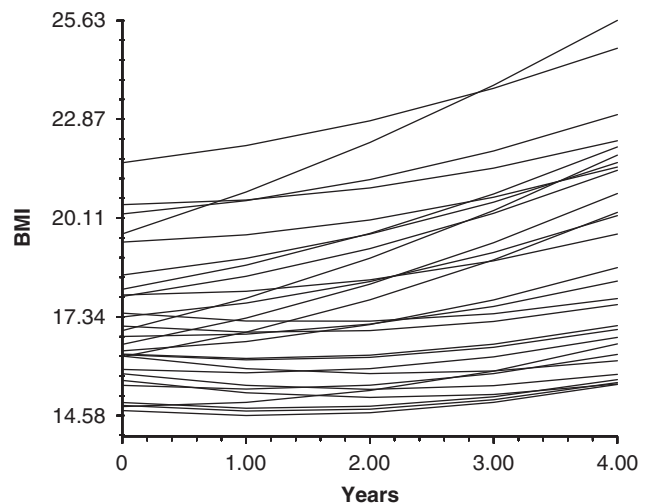

Figure 1 Fitted curves of a random sample of 10% of all subjects disregarding their gender (years are centred such that 0 corresponds to 6 years, 1–7 years and so on).

Table 1 Mean (± s.d.) values for BMI, 1-mile, PA and KTK in boys and girls, at the five different time points

	6 years	7 years	8 years	9 years	10 years
BMI					
♀	17.15 ± 2.32	17.22 ± 2.71	17.85 ± 2.83	18.15 ± 3.30	19.12 ± 3.58
♂	17.33 ± 2.51	17.42 ± 2.76	17.98 ± 3.14	18.14 ± 3.50	19.12 ± 3.67
1-mile					
♀	14.05 ± 2.80	14.65 ± 3.31	14.10 ± 2.69	13.73 ± 2.34	13.27 ± 2.61
♂	13.06 ± 2.69	13.63 ± 3.95	13.41 ± 3.53	12.32 ± 2.80	11.30 ± 3.02
PA					
♀	45.64 ± 32.65	36.09 ± 21.51	35.82 ± 29.33	35.28 ± 18.75	27.94 ± 16.16
♂	51 ± 31.85	44.42 ± 24.86	50.74 ± 21.47	52.15 ± 22.47	41.97 ± 19.69
KTK					
♀	70.27 ± 12.69	74.96 ± 13.53	78.00 ± 14.11	71.91 ± 16.34	
♂	82.30 ± 12.39	82.37 ± 14.21	80.57 ± 14.47	81.16 ± 15.57	

Abbreviations: BMI, body mass index; KTK, Körperkoordination test für Kinder; PA, physical activity.

Table 2 Growth model 1 estimating BMI trajectories of children between 6 and 10 years of age

Fixed effects	Coefficient	s.e.	t-ratio	P-value
BMI (baseline)	17.2383	0.1438	119.89	<0.001
Time (slope)	0.0311	0.0536	0.58	0.589
Time (acceleration)^2	0.1069	0.0120	8.92	<0.001

Random effects	Variance	df	χ^2	P-value
BMI (baseline)	5.57138	283	4801.73	<0.001
Time (slope)	0.19582	283	1169.25	<0.001
Level error 1	0.56488			

| Deviance | | | 4488.94 | |
| No of parameters | | | 7 | |

Abbreviations: BMI, body mass index; s.e., standard error.

Table 3 Growth model 2 estimating BMI trajectories of children between 6 and 10 years after adding PA, 1-mile and KTK (as time-varying predictors)

Fixed effects	Coefficient	s.e.	t-ratio	P-value
BMI (baseline)	17.5220	0.3782	46.33	<0.001
Time (slope)	0.1887	0.0696	2.71	0.007
Time (acceleration)^2	0.0511	0.0239	2.14	0.032
PA	0.0005	0.0015	0.31	0.754
1-mile	0.0198	0.0127	1.56	0.119
KTK	−0.0080	0.0035	−2.27	0.023

Random effects	Variance	df	χ^2	P-value
BMI (baseline)	5.34257	282	3940.03	<0.001
Time (slope)	0.20942	282	754.01	<0.001
Level error 1	0.57094			
Deviance			3648.66	
No of parameters			10	

Abbreviations: BMI, body mass index; KTK, Körperkoordination test für Kinder; PA, physical activity; s.e., standard error.

Table 4 Growth model 3 estimating BMI trajectories of children between 6 and 10 years, after adding PA, 1-mile and KTK (as time-varying predictors) and gender (time invariant predictor)

Fixed effects	Coefficient	s.e.	t-ratio	P-value
BMI (baseline)	17.5034	0.4062	43.09	<0.001
Gender	0.1591	0.2875	0.55	0.580
Time (slope)	0.2320	0.0774	3.00	0.003
Gender (slope)	−0.0790	0.0706	−1.12	0.264
Time (acceleration)^2	0.0501	0.0240	2.09	0.037
PA	0.0005	0.0015	0.37	0.712
1-mile	0.0198	0.0128	1.56	0.120
KTK	−0.0089	0.0037	−2.42	0.016

Random effects	Variance	df	χ^2	P-value
BMI (baseline)	5.32818	281	3925.78	<0.001
Time (slope)	0.20757	281	749.57	<0.001
Level error 1	0.57171			
Deviance			3646.63	
No of parameters			12	

Abbreviations: BMI, body mass index; KTK, Körperkoordination test für Kinder; PA, physical activity; s.e., standard error.

should also be noted that the BMI-slope, that is mean velocity, is now statistically significant ($P = 0.007$).

In Model 3, gender was added to the previous model. We wanted to know whether gender would be a significant predictor of baseline BMI values and if boys and girls had different mean changes over time (Table 4). No significant gender effects were found, and the fit of this model is not better than Model 2 ($\chi^2(2) = 2.033$, $P = 0.363$).

Discussion

The primary aim of this study was to model longitudinal changes in BMI and its putative correlates over a period of 5 years in Azores children. The best fitting model of BMI changes over time (Model 1) showed no significant

(0.0311 ± 0.0536, $P = 0.589$) changes in velocity, which is different from Danner's[12] results in US children (0.2104 ± 0.0065, $P < 0.01$). This flattening of the curve in Portuguese children, may be related to the adiposity rebound which generally occurs between 3 and 7 years of age.[27] Adiposity rebound corresponds to an increase in number of fat cells after an earlier phase of the cells increasing then decreasing in size. Rolland-Cachera et al.[27] noted that the age that the rebound occurs (the age at adiposity rebound) predicts later fatness, an earlier rebound predicting greater fatness in adolescents[2] and adults.[28] In addition, the correlation of BMI values at 6 years of age and growth rate was 0.54 and in the US children reported by Danner[12] was 0.45. This association implies steeper BMI changes for those children with higher BMI values at 8 years of age, which references a close monitoring of height changes and possible associations with nutrition habits and PA levels.

A significant random effect in inter-individual slopes is indicative of relevant heterogeneity in adiposity rebound, that is, no parallelism of BMI trajectories, this was also found in the US sample followed longitudinally from 5 to 11 years.[12] The non-linear shape of BMI trajectories is shown by the time[29] parameter is similar to charts of BMI of French children[30] and more recently in charts for British children and youth.[31] The natural history of BMI is similar to that for body fat, a steep rise during infancy with a peak at 9 months of age, followed by a fall until age 6 years and then a second rise, which lasts until adulthood.[31] This trend is well illustrated in the percentile distribution of BMI growth charts (CDC, 2000) across age where adiposity rebound is expected to occur. In addition, Malina et al.[32] showed that the interpretation of the new growth charts for US children of BMI-for-age percentiles for boys and girls from 2 to 20 years of age (Centers for Disease Control and Prevention, 2000) as an indicator of fatness needs to be done with care. An elevated BMI is not necessarily indicative of excess fatness. Children with the same BMI will likely differ considerably in percentage fat and total body fat, indicating limits to BMI as an indicator of fatness in children and adolescents, as BMI is more of an indicator of heaviness and indirectly of body fat.[32]

This study shows that changes in BMI are not uniform across individuals and that inter-individual variability is present in BMI changes that is, no significant tracking. Tracking is generally addressed with age-to-age correlations.[33] Although this approach is reliable, it does not test any specific meaning of tracking which Foulkes and Davies[25] γ does taking into account all data structure across all time points. Hesketh et al.,[33] however, observed, in a sample of Australian children, a high correlation ($R = 0.84$) between BMI Z-score at baseline and follow-up (3 years) for the overall sample, in males ($R = 0.83$) and in females ($R = 0.85$), as well for all age groups (all $R = 0.80$). During middle childhood, the incidence of overweight/obesity exceeds the proportion of children resolving to non-overweight. However, for most children adiposity remains stable, and stability appears to

increase with age.[33] Differences in tracking results may be explained not only by the statistic used and by the underlying concept of tracking[26] but also by the sample size (1438 Australian children aged 5–10 years, compared with 285 children in Azores islands), as well as the frequency of measurements taken in the study.

When the time-varying predictors were included in Model 2, the BMI velocity parameter was significant ($P = 0.007$). This change, compared to Model 1, can be explained by the additive effects that PA, 1-mile and KTK (but only significantly with gross motor coordination) may have on the growth of BMI. These variables are indicators of the operation of the motor functions of the entire body and its constituent segments, as in locomotor activities (gross motor activities) and the environmental factors that are often viewed as exerting a favorable influence on growth and maturation.

In this study PA showed no association with BMI trajectories, indicating that PA does not appear to have a direct influence on the development of BMI in this sample of children. These results are similar to those of Ribeiro et al.[10] who did not find significant differences in PA-levels among Portuguese children of both sexes aged 8–16 years grouped into BMI quartiles. Also, Carvalhal et al.[34] found no association between PA and BMI in Portuguese children between 7 and 9 years of age. These Portuguese studies are supported by the work of Maffeis et al.,[35] which showed that PA did not affect changes in BMI over a 4-year period in children aged 8–10. In this study PA levels were assessed by means of a questionnaire filled out by the parents together with a pediatrician. In contrast, a longitudinal study by Gouveia et al.[36] which followed children and adolescent between 7–18 years of age for 3 years in the Madeira islands, observed a weak relationship with PA (assessed by the Baecke questionnaire) and BMI changes.

Abbott and Davies,[37] in Australian children aged between 5 and 10 years, found that time spent in vigorous and hard intensity activities (monitored by accelerometry) were significantly correlated with percentage body fat ($R = -0.44$, $P < 0.004$ in girls and $R = -0.39$, $P < 0.014$ in boys), but not to BMI. Further, Utter et al.[13] concluded that PA (assessed with a modified version of the Physical Activity Questionnaire for Children (PAQ-C)) was inversely associated with BMI when demographic variables were controlled for, but this relationship lost significance in a multivariate model with the total sample of 3275 children aged 5–14 years from New Zealand. Jago et al.[38] conclude that PA was negatively associated with BMI among a tri-ethnic cohort of 3–4-year old children followed for 3 years, and that it was a negative association. Heart rate monitoring and children's activity rating scale observation were used to assess PA.

The assessment of PA in childhood and adolescence is a complex task, hampered by methodological difficulties, as the measures vary in the specificity of their assessment of mode, frequency, intensity and duration of activities as well as in the cultural context.[39] These factors can explain differences in results across studies, which in part can be attributed to the differences in study design. However, if BMI changes are to be noticed they may be attributable to additive and interactive effects of moderate-to-vigorous activity and proper nutrition.[40]

Aerobic fitness measured by the 1-mile run/walk did not affect the BMI trajectories in the 5-year period. Being fast or slow in running the distance does not change interindividual BMI values over time. This was an unexpected finding. For example, Beets and Pitetti[29] in a cross-sectional study, revealed the existence of noticeable variation in 1-mile run/walk times and BMI in white non-Hispanics and their ethnic peers for both males and females between 10 and 15 years of age. Kim et al.[14] have found, that not passing an endurance run test was associated with overweight incidence in both boys and girls, aged between 5–13 years. After adjusting for baseline BMI, the endurance run remained a significant predictor of incident overweight among girls.[14]

In a literature review about PA and cardiovascular fitness by Morrow and Freedson[41] it was concluded that there was a an average 0.16–0.17 correlation between the two, suggesting that other factors could be involved in the variability of PA and cardiovascular fitness. Although the link between PA and cardiovascular fitness is low to moderate at best, more active youths generally perform better on endurance tests (for example, 12-min run and 1-mile run/walk).[32] In this study, even when we tested for an interaction of PA and aerobic fitness we did not find any significant association with BMI changes (results not shown).

Gross motor coordination was significantly associated with changes in children's BMI. Children with better scores in motor coordination had lower BMIs. This finding is in accordance with the cross-sectional study of Graf et al.[15] in primary schools, who also found an inverse correlation between KTK and BMI. This association was found in girls (BMI $R = -0.209$; $P < 0.001$) and boys (BMI $R = -0.164$; $P < 0.006$). Craf et al.[15] also showed that children who are more active—either in organized physical education settings and/or on a regular basis—do have better gross motor development. The directionality of the relationship between gross motor co-ordination and BMI is difficult to infer from cross-sectional data. It is probable that individuals with better coordination are more apt to undertake PA, which will ultimately affect BMI, but it is also probable that individuals with a lower BMI may have greater motor coordination because of lower levels of body fat, which may affect negatively on agility.

This study has several limitations. First, the use of a self-reported questionnaire to assess PA is not always optimal given the difficulty of children to recall and quantify their activities. However we have frequently reported high reliability values from children of different geographical regions in Portugal.[42,22,43–45] Given recent technological advances, future studies can now begin incorporating more direct measures of PA into their designs. Second, although we have sampled only 285 children from both genders,

1492

justified by the fact that children were assessed five times during the follow-up period, we had enough power to detect significant results; moreover with this sample size and the number of measurement occasions we were able to have precise parameter estimates given the small standard errors. Third, the 1-mile run/walk test is not without problems, especially in children. One of the major problems with this test is the participant's capacity to develop an appropriate pace although the children's performance is quite reliable. A recent study found moderate evidence that this test is valid for assessing cardiorespiratory fitness,[46] although their younger ages started at 8 years. There is also the case of using the 20 m shuttle run as an alternative which has been proven quite valid and reliable.[47] However, it is important to test for the validity of different regression equations to predict VO_2 max in children as well as the cross-validation of such equations in different samples of the same population. We are also aware that it would be appropriate to use direct laboratory measures. However, this would be very difficult to implement in field studies in the four islands because of financial and technical reasons and also because of practicality. In future studies, the use of other anthropometric measurements for body composition indicators (for example, skinfolds and waist circumference) could be considered in conjunction with proper statistical analysis given the need for cross-validation of specific formulas to estimate body fat.

Conclusions

In summary, BMI trajectories of both boys and girls show considerable crossing from 6 to 10 years, indicating low tracking. Considerable inter-individual variation exists both in baseline BMI-values and changes (velocity and acceleration) over time. PA and fitness were not associated with BMI-changes, but gross motor function was negatively associated with BMI-changes. No gender-specific associations were found. If confirmed in other populations these observations could be translated in the promotion of PAs that improve gross motor function in children aged 6–10 years. This seems to be of major importance for the physical education curriculum of primary school children. In addition, such programmes need to be tested for their effectiveness.

Conflict of interest

The authors declare no conflict of interest.

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