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MONOGRAPH
Physical activity and its impact on brain development and learning

Showcasing the Chilean Cogni-Action Project: Connections between physical, cognitive and socioeconomic factors in a large sample of schoolchildren

Showcasing the Chilean Cogni-Action Project

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Anya Doherty and Carlos Cristi-Montero wrote the first version of the manuscript, Ricardo Martinez-Flores, Humberto Peña-Jorquera, and Juan Pablo Espinoza-Puelles did revision and correcting, and Humberto Peña-Jorquera designed Figure 1.

Ethical statement
The Cogni-Action Project was conducted according to the guidelines of the Declaration of Helsinki and approved by the Bioethics and Biosafety Committee of the Pontificia Universidad Católica de Valparaíso (BIOEPUCV-H103–2016) and was retrospectively registered (8/July/2020) in the Research Registry (ID: researchregistry5791).

Access to materials
Access to the Cogni-Action Project website at https://carloscristi.wixsite.com/cogn

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Abstract

In recent decades, there has been growing global concern about alarming rates of obesity, sedentary lifestyles, insufficient levels of physical activity and fitness, and unhealthy eating habits among children and adolescents. At the same time, we have witnessed an increase in global poverty and socio-economic vulnerability. Understanding the intrinsic relationship between physical and cognitive health is crucial, and there is growing evidence of a significant link. However, over 80% of existing data is from high-income countries, which represent a negligible proportion of the world's children. UNICEF projections indicate that by 2030, approximately 63% of the world's children and adolescents will live in low- and lower-middle-income countries. This highlights a significant knowledge gap that the Cogni-Action project in Chile is helping to fill. In particular, Chile faces significant challenges, with a childhood overweight and obesity rate of 54%, the highest levels of sedentary behaviour, physical inactivity and sugar-sweetened soft drink consumption, and stagnating educational attainment. Wealth inequality is also high, with the top 10% of the population owning 77% of the wealth. Chile's Cogni-Action project collected comprehensive data over three years (2017-2019) from 1,296 school children (10-14 years old) in the Valparaíso region. These data included 789 variables covering physical, psychosocial, cognitive and lifestyle factors, as well as neuroimaging variables. This article aims to contextualise and present this project on the basis of the papers published to date. As universities and research institutions around the world undertake similar endeavours, there is a need to share findings and methodologies to accelerate the development of knowledge that can inform public policy and shape the agendas of relevant institutions.

Keywords: cognitive performance; nutritional status; physical fitness; body composition; healthy diet; socioeconomic vulnerability

Resum

En les últimes dècades, hi ha hagut una creixent preocupació global per les alarmants taxes d'obesitat, els estils de vida sedentaris, els nivells insuficients d'activitat física i fitness i els hàbits alimentaris poc saludables entre els nens i adolescents. Al mateix temps, hem estat testimonis d'un augment de la pobresa global i de la vulnerabilitat socioeconòmica. Entendre la relació intrínseca entre salut física i cognitiva és crucial, i hi ha evidències creixents d'un vincle significatiu. No obstant això, més del 80% de les dades existents procedeixen de països de renda alta, que representen una proporció insignificant dels nens del món. Les projeccions d'UNICEF indiquen que, per a 2030, aproximadament el 63% dels nens i adolescents del món viuran en països de renda mitjana i baixa. Això posa de manifest una manca significativa de coneixement que el projecte Cogni-Action a Xile està ajudant a omplir. En particular, Xile s'enfronta a reptes importants, amb una taxa de sobrepès i obesitat infantil del 54%, els nivells més alts de comportament sedentari, inactivitat física i consum de refrescos amb sucre i estancament de l'assoliment educatiu. La desigualtat de riquesa també és alta, amb el 10% més alt de la població que posseeix el 77% de la riquesa. El projecte de Xile Cogni-Action va recollir dades completes durant tres anys (2017-2019) de 1.296 escolars (10-14 anys) a la regió de Valparaíso. Aquestes dades van incloure 789 variables que cobreixen factors físics, psicosocials, cognitius i d'estil de vida, així com variables de neuroimatge. Aquest article té com a objectiu contextualitzar i presentar aquest projecte a partir dels articles publicats fins ara. A mesura que les universitats i les institucions de recerca de tot el món duen a terme esforços similars, és necessari compartir troballes i metodologies per accelerar el desenvolupament de coneixements que puguin informar les polítiques públiques i donar forma a les agendes de les institucions pertinents.

Paraules clau: rendiment cognitiu; estat nutricional; estat físic; composició corporal; dieta saludable; vulnerabilitat socioeconómica

Presentation

The central aim of this article is to introduce the Cogni-Action project and encourage readers and researchers to visit the project website and read the nine articles published to date. This article provides background information on the context in which the Cogni-Action Project was born, and presents an overview of key indicators of physical health and lifestyle factors at the global and Chilean levels. We also highlight the implications of these health statistics for academic and cognitive performance. The article examines the relevance and peculiarities of the Chilean context and how Cogni-Action helps to compensate for the lack of data for countries with this social profile. We present the project itself and a brief synthesis of the main findings of the papers published so far. Finally, we highlight some of the questions and challenges that emerge from the research and their relevance on a broader scale.

The global context

Global figures for indicators of healthy lifestyles among children and adolescents have become a growing concern for national governments and international organisations in recent years, including the World Health Organization (WHO), the United Nations Children's Fund (UNICEF) and the Organisation for Economic Co-operation and Development (OECD). Rates of obesity, sedentary lifestyles, physical inactivity and unhealthy eating habits, as well as mental health indicators such as stress, have risen sharply, particularly since the global SARS/Covid-19 pandemic. Childhood overweight and obesity are increasing to the point that they are now considered

an epidemic or global emergency by global organisations[1,2]. WHO Member States have endorsed the target of zero increase in childhood obesity by 2025[3]. These data are relevant not only for their impact on physical health, but also on cognitive development and performance[4].

If we examine another set of physical health markers that have been shown to influence cognition, namely physical activity and fitness, recent WHO studies indicate that 81% of adolescents aged 11-17 years are insufficiently physically active and excessively sedentary[5,6]. Most studies have been conducted in high- and middle-income countries (HICs and MHICs), indicating a research gap for low- and middle-income countries (LICs and LMICs)[7].

The 2021 Global Matrix 4.0 report of the Active Healthy Kids Global Alliance[8] provides compelling evidence from 57 countries. The report assesses children and adolescents in 10 subcategories of physical activity. In short, the evidence shows that, globally, only a small percentage of adolescent schoolchildren meet recommended levels of physical activity, fitness, sleep duration and healthy diet, with high rates of sedentarism and overweight/obesity[5].

While these indicators of physical health are important in their own right, they have added value in that they are not disconnected from brain health, cognitive performance and academic outcomes. Recent research suggests that the health-related behaviours of children and adolescents have a potentially powerful impact on brain development, structure and function, and on cognitive and academic outcomes[9,10]. A growing body of research points to associations between cognitive performance and academic outcomes and lifestyle and well-being variables, such as physical activity and fitness[11-13], sedentariness[14], overweight/obesity[4,15], healthy eating[16,17], sleep quality[18-20], socioeconomic status[21-23], among others. In a meta-analysis by Jirout et al[10], the authors describe the relevance of these and similar variables, taking an ecological and complex systems approach to children's cognitive performance.

Two key concepts are highlighted: complexity and neuroplasticity. As noted by Tokuhama-Espinosa & Nouri[24], the brain is a dynamic, complex system, and through mechanisms of neuroplasticity, environmental factors and individual experiences leave their imprint on brain health and development. These factors may be negative, risk factors, or positive, neuroprotective factors. This is the relevance of the Cogni-Action project, which aims to explore the links between these factors, with a specific focus on the cognitive performance of Chilean adolescents. It should be emphasised that adolescence is a particularly important period in which key habits are acquired and critical neural reorganisations take place[25], which will have an impact on the individual's future life prospects and fulfilment[26,27]. This important period of life will be explored and analysed through the data provided by the Cogni-Action project. In addition, the project contributes valuable data and potential insights into the lay of the land, with empirical contributions from the Chilean reality, a middle-income country for which data in these research areas are lacking.

The relevance of the Chilean case

At present, the literature on the effects of chronic physical activity on cognitive performance, academic outcomes and brain function comes predominantly from developed countries[7], with a paucity of high-quality data for the Latin American and Chilean contexts. Developed countries, where most of the research in this area has been conducted, have different indices of socioeconomic wealth and inequality compared to LICS and LMIC, and represent a minimal proportion of the world's children[7]. UNICEF predicts that by 2030, LICs and LMICs will be home to approximately 63% of the world's children and adolescents[28]. In this sense, it is relevant that social vulnerability has a detrimental effect on children's brain health, cognition and academic performance[21,29]. Chile, a developing Latin American country that is also a member of the OECD, has a significant income inequality rate of 44.4% according to the 2020 Gini index, and wealth concentration is extreme, with 1% of the population owning 49.6% of the wealth[30].

Poverty, a vulnerable social environment and low socioeconomic status have a significant impact on brain health, brain function and cognition[23,21], as well as on future income and socioeconomic status across the lifespan[27,31]. In short, children from disadvantaged backgrounds have poorer overall cognitive performance[32]. Since 2006, in an attempt to address this challenge, the Chilean state has developed the School Vulnerability Index (SVI), a complex, multivariate tool that assesses socioeconomic and demographic vulnerability and informs public policy to

mitigate the impact of poverty on vulnerable school populations and prevent school dropout[5]. High levels of vulnerability are concentrated in public schools, accompanied by a geographical segmentation factor indicating that poor neighbourhoods have more students attending public schools and where the vulnerable population is concentrated.

In addition to what has been mentioned, until 2017-2018 the Chilean education system (during the development of the Cogni-Action project) consisted of three types of schools: private, subsidised and public. This reflects the socio-economic fragmentation, with high-income families sending their children to schools with better results, even moving to the places where they are, increasing the segmentation that accompanies vulnerability[33]. The education system thus replicates and exacerbates socio-economic inequalities[33]. Disadvantaged learning environments negatively affect the cognitive and academic performance of poor children[34].

The 2021 Global Matrix 4.0 report on Chile confirms the very low levels of overall physical activity. Out of 57 countries evaluated from six continents, Chile ranks fifth among countries with the most sedentary lifestyles and the lowest overall levels of physical activity, with only 16.5% of children and adolescents being physically active. According to a WHO report, Chile is the second most overweight and obese country in the OECD, with 74.2% of the adult population affected[3], meaning that approximately three out of four people are overweight or obese. The 2022 report of Chile's National Council for School Aid and Subsidies, the Junta Nacional de Auxilio Escolar y Becas, shows a progressive increase in overall obesity among schoolchildren, reaching 58.3% by the end of 2021[35]. At the same time, educational outcomes, as assessed by the OECD Programme for International Student Assessment (PISA) and the Chilean SIMCE (Sistema Nacional de Evaluación de Aprendizajes), have not improved, despite the implementation of various educational policies and programmes[36,37].

This outline of the Chilean context provides the background to the emergence of the Cogni-Action project, which we present below.

Showcasing the Cogni-Action Project

"Cogni-Action: Physical Activity as a Mediator of Cognitive Development in School Children" is a project funded by the National Fund for Scientific and Technological Development (FONDECYT, 11160703), Chile. It was carried out between March 2017 and October 2019. The project was carried out according to the guidelines of the Declaration of Helsinki and approved by the Bioethics and Biosafety Committee of the Pontificia Universidad Católica de Valparaíso (BIOEPUCV-H103-2016) and was retroactively registered (8/July/2020) in the Research Registry (ID: researchregistry5791). As the name suggests, the project is inspired by the belief, firmly based on existing empirical evidence, that physical well-being is associated with cognitive and academic performance[38,39]. The project is both innovative and complex, as it aims to build a database of remarkable volume and heterogeneity, thereby contributing to the narrative that explains the reality of a generation of Chilean schoolchildren. It also stands out for the context in which it was born: a middle-income country with high levels of inequality and a limited critical mass of researchers.

Led by researcher Dr Carlos Cristi-Montero of the Pontificia Universidad Católica de Valparaíso (PUCV), the project took on the ambitious task of collecting data from 1,586 students aged between 10 and 14 from 19 public, subsidised and private schools in the Valparaíso region. From this initial number, a total of 1,296 students (50% girls) were eventually included in the study. This age group was chosen because of its limited scope, in order to avoid possible methodological biases due to the critical period in which pre-adolescents and adolescents go through the development of different personal characteristics.

The project aims to contribute to the knowledge generated on this subject in Chile and beyond. It also aims to promote a re-evaluation and a new appreciation of physical education in Chilean society, demonstrating - through scientific evidence - that its role in education can go beyond its effects on physical health and signal an important role as a mediator of cognition. In this way, new opportunities could be opened up for our students, despite their socio-cultural and socio-economic contexts. Below we present a brief written summary and a graphic illustration of the findings of the nine published articles resulting from the Cogni-Action project. Further details of the project and links to these articles can be found on the project website (https://carloscristi.wixsite.com/cogn).

Cogni-Action Project publications

To date, nine studies from the extensive Cogni-Action database have been published in Q1 (k=8) and Q2 (k=1) journals, contributing to the dissemination of new knowledge in the field. However, much remains to be analysed and published from the large body of evidence collected. In this section we present the central ideas of these Cogni-Action articles, visually summarised in **Figure 1**. We do not go into detail about methodology or findings, as these are readily available in the original articles, which are listed in the bibliography.

(i) The Cogni-Action Project study protocol and rationale.

The first publication from the Cogni-Action Project database was the article by **Solis-Urra et al**. entitled "Study protocol and rationale of the Cogni-Action Project a cross-sectional and randomised controlled trial about physical activity, brain health, cognition, and educational achievement in schoolchildren"[40]. This article is a good starting point for an overview of the main focus of the project.

(ii) Fitness associated with cognitive performance.

Solis-Urra et al (2021) conducted this study entitled

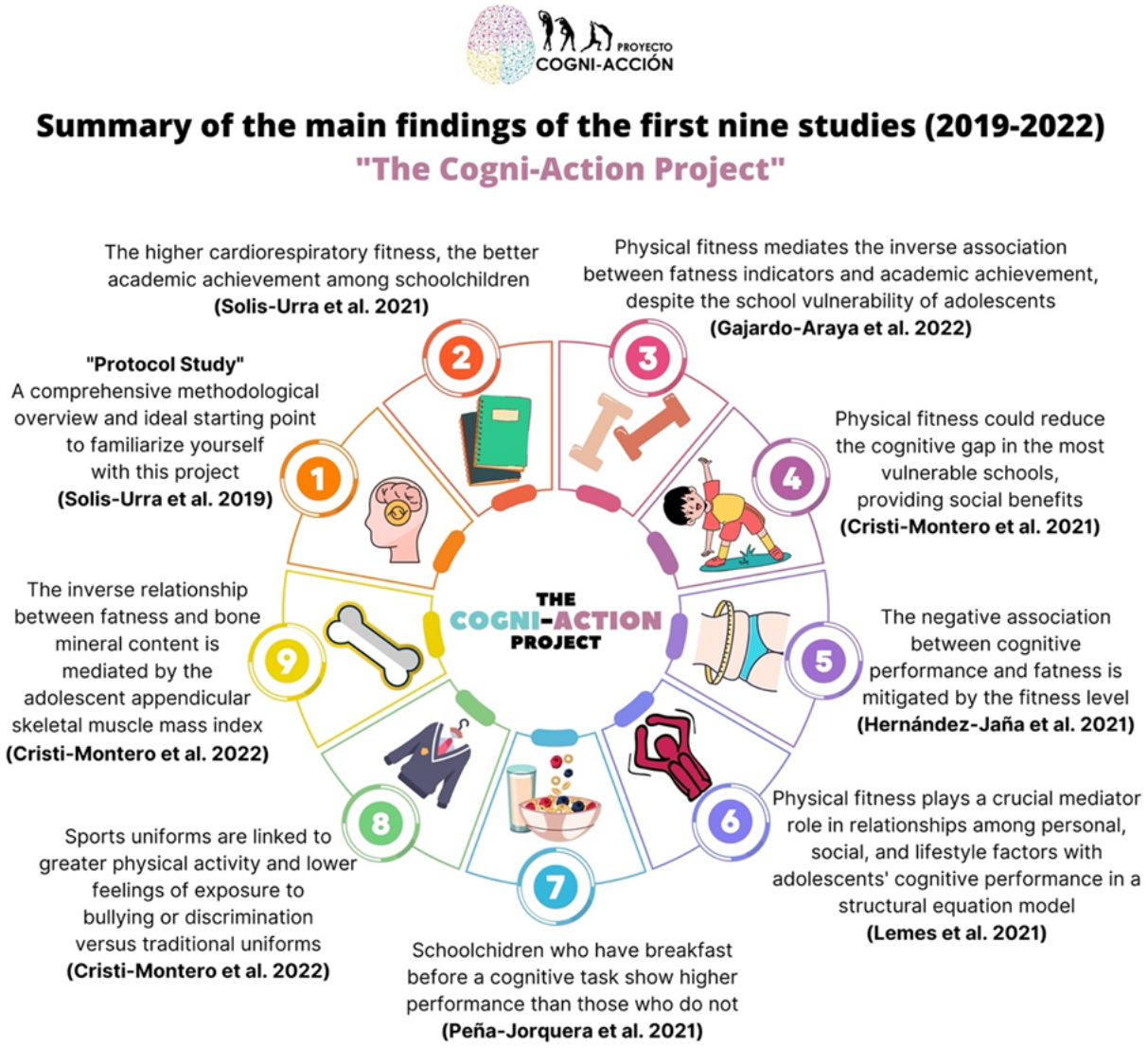

Figure 1. Summary of the main findings of the first nine studies (2019-2022). Source: Elaboration by Humberto Peña-Jorquera for this article

"Physical Fitness and its Association with Cognitive Performance in Chilean Schoolchildren: The Cogni-Action Project' to investigate the relationship between fitness levels and cognitive performance in schoolchildren[41].

(iii) Fitness as mediator between fatness and academic achievement. The study by **Gajardo-Araya et al.** 'Physical Fitness Mediates the Inverse Association between Fatness Indicators and Academic Achievement, despite the School Vulnerability of Adolescents - The Cogni-Action Project' (2022)[42] examined the mediating role of fitness between fatness and academic achievement, with the additional variable of vulnerability.

(iv) Fitness as a mediator or protective factor between vulnerability and cognition.
To further explore the relationship between fitness, cognition and vulnerability, Cristi-**Montero et al.** (2021) published their findings in a new study, "Could Physical Fitness Be Considered as a Protective Social Factor Associated with Bridging the Cognitive Gap Related to School Vulnerability in Adolescents? The Cogni-Action Project"[43]. The study aimed firstly to compare differences between different levels of school vulnerability, fitness levels and their association with cognitive performance in adolescents. It also aimed to determine the mediating role of fitness in the relationship between school vulnerability and cognitive performance.

(v) Physical fitness mediates fatness-cognitive performance association, with school vulnerability taken into account.
Hernández-Jaña et al (2021) further explore the mediating role of physical fitness in the relationship between adiposity and cognitive performance, with the aim of identifying the influence of school vulnerability[44]. The basic idea of this research is that physical fitness and adiposity together modulate cognitive abilities, which in turn are related to the socio-economic background of the participants.

(vi) Physical fitness buffers the relationship between SVI-cognitive performance, and fatness-cognitive performance.
Research by **Lemes et al** (2021) clarifies that physical fitness plays a mediating or buffering role between vulnerability and cognitive performance, and between fatness-obesity and cognitive performance, and details the mediating relationships between these sets of relationships[45].

(vii) Breakfast is linked to better cognitive performance.
In this review, the focus of the research shifts to the importance of a healthy diet for cognitive performance. The study by **Peña-Jorquera et al** (2021) aimed to analyse the effect of breakfast on cognitive performance[46].

(viii) Traditional versus sports uniforms: associations with physical activity, academic performance and fear of bullying
This article by **Cristi-Montero et al.**[47] explores the associations between an interestingly heterogeneous set of variables and aimed to explore possible associations of traditional school uniforms (TUs) and sports uniforms (SUs) with the variables of academic performance, cognitive performance, playtime, bullying and discrimination in participants. The influence of SVI was simultaneously investigated.

(ix) How muscular fitness can mitigate the impact of fatness on bone health.
This, the most recently published Cogni-Action study by **Cristi-Montero et al** (2022), focused specifically on physical health-related variables in the school context[48]. It examined the relationship between four different measures of adiposity, bone mineral content and appendicular skeletal muscle mass index.

Discussion

In this overview of the Cogni-Action project, a central theme emerges: the vital role of physical fitness in cognition and academic performance. Most studies of this kind have tended to be conducted in wealthy countries, with the contextual realities of HICs. In this sense, the Cogni-Action project contributes to the growing knowledge base from the perspective of other socio-economic and socio-political realities. One possible implication of this research is that fitness can be leveraged - through physical activity programmes in schools - as both factors have been shown to be associated with cognitive performance and academic outcomes. What we can conclude

from the research analyses reviewed above is that schools may wish to consider increasing physical activity levels and improving fitness levels, not only for the sake of physical health and well-being and to combat physical health risks such as sedentary lifestyles, overweight and obesity, but also because of their association with cognitive and academic performance.

In addition, these studies highlight the mediating or buffering role of fitness, in the sense that it can 'mitigate' the deleterious effects of socio-economic vulnerability, overweight and obesity. As noted above, poverty and adverse socio-economic conditions have a negative impact on children's overall development, including brain development and cognitive performance. Therefore, if fitness has the potential to play a buffering or mitigating role in these adverse contexts, preserving and protecting cognitive performance; and if it also plays this protective role in the face of other physical and brain health risks, such as sedentary lifestyles, physical inactivity, overweight and obesity, it could be incorporated into the strategic goals of educational institutions and school curricula as a means of protecting and promoting cognitive well-being and performance in school children.

It is worth mentioning the relevance of the study by Peña Jorquera et al.[46] on the importance of breakfast consumption for cognitive performance and, conversely, the negative association between breakfast skipping behaviour and cognitive performance, with particularly relevant results for overweight/obese participants. This study, like that of Lemes et al[45], includes health and lifestyle variables that appear to be related to cognition in increasingly complex ways. The underlying understanding is that the relationships between variables are not simple, causal or one-dimensional. It seems necessary to enrich our analyses with complex multivariate statistical methods. In line with this gradual move towards complexity, Doherty's doctoral thesis[49] explores the interplay between ten variables from the Cogni-Action database and, using network analysis, identifies fitness as the variable with the greatest strength, while physical activity and healthy diet emerge as factors on which interventions can be made to realign the relationships across the network (expected influence).

If teaching and learning institutions could draw broad conclusions from these studies and isolate a few key variables from the nine studies examined, they could tentatively be summarised as follows: that several healthy lifestyle habits converge in a positive association with cognitive and academic performance in adolescents.

Interpretation of the data from the Cogni-Action project, which includes neuroimaging, electrophysiology and other variables, is still ongoing. We hope that future findings will go a long way towards bridging the geographical gap in this important area of research. It is also important to emphasise that our current findings are based on cross-sectional data, which requires caution when extrapolating to different contexts and cultures. The Cogni Action contributes to a comprehensive understanding of the relationship between healthy lifestyles and cognition, mental health and brain function for biomedical, public health and educational perspectives.

Conclusions

Research groups from various universities around the world have consistently contributed to empirical research on the importance of a complex perspective on brain-body interactions in learning environments. This complexity is based on a number of principles that underlie the articles we have briefly referred to here. The Cogni-Action project is a step towards a more complex perspective on the variables associated with cognitive and academic performance in adolescents. In the context of a world that increasingly recognises complexity, educational contexts should in turn incorporate complex and multivariate analyses of a wide range of factors that potentially intervene in cognitive and academic performance. Part of the exceptional nature of the Cogni-Action project lies in its geo-political and socio-economic contextualisation. The idiosyncratic nature of the Chilean case requires us to pay attention to social, cultural, economic and political considerations that differ from those of the HICs where the bulk of the research has been carried out to date. Hence the importance of the initial results of the Cogni-Action project as a contribution to filling this existing research gap.

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