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Exploration of socio-ecological variables to protect against physical activity drop out during lockdown

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Abstract.

Introduction with Problem Statement and Approach, Material and Methods, Results, Discussion, Conclusions

Problem Statement. The lockdown against coronavirus 2019 pandemic has led to a decrease in physical activity (PA), but any study has analyzed PA' evolution during this transition following the social-ecological theoretical framework of human development. It suggests that PA engagement depends on the interaction of individual, interpersonal and environmental determinants. This model is essential to better understand PA engagement and to prevent future crises. **Purpose.** This study investigated the evolution of adolescents' PA with their protective and inhibitory barriers according to ecological model of PA engagement. **Methods.** A longitudinal follow-up of 808 French adolescents between before and during lockdown were questioned from PA and socio-demographic data. Wilcoxon signed rank test and Boruta forest algorithm were used to quantify the evolution of each PA intensity and to identify protective and inhibitory socio-ecological's determinants on PA behaviour. **Results.** Our results showed a significant decrease in the overall PA (-231 Mets.min.week⁻¹, $p < .05$). More specifically, low PA decreased significantly (-480 Mets.min.week⁻¹, $p < .05$), while moderate and vigorous PA has remained significantly stable during the lockdown (+0 Mets.min.week⁻¹, $p < .05$). The three determinants of the socio-ecological framework are included in the model of evolution of each PA' intensity. Individual (PA initial profile, 58.8 median importance score) and environmental (garden: 10.42; housing: 7.93 median importance score) determinants are the two most important. Interpersonal determinants have not a significantly importance to explain PA' evolution. **Conclusions.** This study highlighted the complex and non-linear process of PA engagement at a critical period where the determinants are being disrupted. Socio-ecological tools are identified to rethink prevention strategies adapted to future crisis periods. Future interventions to promote PA should not target one determinant of the system but should consider the interactions of all socio-ecological variables.

Keywords: coronavirus, health, intensity, correlates, Boruta

Introduction.

The global coronavirus 2019 pandemic led many governments to confine the population (from 16 March to 11 May 2020 in France). This lockdown was designed to slow the spread of the virus but raises the question of possible collateral damage, particularly in terms of physical activity (PA, Castañeda-Babarro et al., 2020). Thought the inaccessibility of sports' infrastructures and the limitation of movement in public places (McDougall et al., 2021), government restrictions have led to an overall decrease in PA (Ammar et al., 2020; Cheval et al., 2021; Hargreaves et al., 2021 López-Valenciano et al., 2021; Stockwell et al., 2021; Wilke et al., 2021), particularly for adolescents (Derigny et al., 2022; Rodríguez-Larrad et al., 2021).

Adolescence, as a key period in the adoption of a physically active lifestyle, represents a period of life which is particularly sensitive to this loss of PA (Varma et al., 2017). Outside lockdown, French adolescents are largely insufficiently active: a cross sectional study between 2002 and 2010 showed that 82% of boys and 92% of girls had a daily PA below World Health Organization (WHO) guidelines (Kalman et al., 2015). In 2020, the WHO established guidelines stating that the amount of PA sufficient for a healthy lifestyle in adolescents (6-17 years) is one hour of moderate to vigorous PA (MVPA) per day. Those recommendations were updated recently (Bull et al., 2020), as additional evidence showed that even low PA (LPA), although less beneficial to health, was worth doing to improve it (Boberska et al., 2018; Ekelund et al., 2016; Poitras et al., 2016; Varma et al., 2014). These recommendations result in the categorisation of adolescents according to their physical lifestyle habits (active, less active and inactive, Génin et al., 2021).

In the lockdown context against covid-19, many studies have investigated the effect of single variables to explain PA changes. For example, effects of gender (Martín-Rodríguez et al., 2021), initial profile of PA

(Genin et al., 2021) or the adaptation of PE teacher according to pedagogical follow-up (Potdevin et al., 2020; Varea & González-Calvo, 2021) were explored. Other studies have highlighted the importance of studying the effects of these variables in interaction, showing more robust and durable outcomes over time, but the contexts were different (Martins et al., 2021).

This lockdown has impacted adolescents' physical life patterns, disrupting the interactions between these variables. The socio-ecological model conceptualised the interaction of these variables and adapted it to the particularities of PA (Bauman et al., 2012; Bronfenbrenner & Morris, 2006). Often used for explaining engagement in PA (Martins et al., 2021), school-based intervention using it have better long terms outcomes (Hynynen et al., 2016). Following this model, the development is understood as a set of interlocking systems in constant interaction, as the relation between the individual and his/her environment could be considered as a set of Russian dolls influencing each other: onto, micro, meso, exo and macro systems (Bronfenbrenner & Morris, 2006). These five systems are dynamic and evolve over time through the chronosystem, referring to a linear and chronological view of events with multiple influences on the other systems. Following this perspective, '*human development is part of a process in which the reciprocal interactions between a bio psychologically active and evolving human organism and the people, objects, and symbols in its immediate environment*' (Bronfenbrenner & Morris, 2006, p. 797).

The literature has shown beneficial effects of certain socio-ecological determinants, like gender or PA level (Génin et al., 2021), PE follow-up, sport social support (Gobbi et al., 2021; Martins et al., 2021) or environmental determinants (Alcántara-Porcuna et al., 2021; Martins et al., 2021). The interaction of these determinants leads to go beyond the traditional definition of PA (Caspersen et al., 1985) and to consider it as a phenomenon situated in a particular dynamic context, as '*people moving, acting and performing within culturally specific spaces and contexts, and influenced by a unique array of interests, emotions, ideas, instructions and relationships*' (Piggin, 2020, p.8). Investigating the evolution of PA required taking a complex and dynamic point of view on the importance of lifestyle for each adolescent. To the best of our knowledges, no study has investigated those variables to analyse the persistence in PA during the context of lockdown against covid-19.

Thus, the objective of the present study was to measure the evolution of each PA' intensity for adolescents during the transition to a lockdown lifestyle, and to investigate the protective or inhibitor effect of each socio-ecological determinants. Inspired by Bronfenbrenner's theoretical framework adapted to PA (Bauman et al., 2012), this study focused on the multifaceted influence of individual (gender and initial levels of PA), interpersonal (PE follow-up and sport social support) and environmental (socio-economic status of the families, localization, housing, presence of garden and sports equipment at home) correlates which were representative of adolescents' lifestyles during lockdown (Génin et al., 2021). According to literature, we hypothesized that the transition from a normal to a lockdown lifestyle led to a significant decrease in vigorous PA and that there were socio-ecological determinants which are protective or inhibitory for PA according to different intensities

Materials and method.

Participants

808 French adolescents (age_{mean} : 16.32±1.01 years old) voluntarily agreed to participate in a longitudinal follow-up of PA measurements between before and during lockdown (March 18 to 30, 2020). During the first week of lockdown, the SNEP (*Syndicat National des Enseignants d'Éducation Physique*), which is the main Union for PE teacher in France, promoted the study to its adherents, who in return proposed it to their students. We included participants if they were attending secondary school, between 14 and 20 years old, subject to necessary agreements to participate (by family and participant). Participants were excluded when survey was not fully completed (n=79) and if data were incoherent (n=42) (e.g., reported participation being more than 7 days a week or more than 10.000 minutes per week). Outliers were excluded using the statistical method of Grubb Test (n=43). This study was authorized by the Ethics Committee of the University of Lille in France under the number 2020-418-S82 and the CNIL (*Conseil National de l'Informatique et des Libertés*) under the number 2020-037.

Measurements

We collected PA's data by IPAQ-SV (International Physical Activity Questionnaire – Short Version), whose reliability level is considered significant for this population ($r_w=.74$, Sember et al., 2020). This transversal survey differentiated PA's intensities over a seven-day retrospective period and classified them to overall PA corresponding as the low, moderate and vigorous PA (LMVPA), low (LPA) and moderate and vigorous PA (MVPA). Following the French national policies on classification of PA's profiles (Genin, 2021), we classified the adolescents into three initial profiles of PA levels undertaken before lockdown: inactive (<600 Mets.min.week⁻¹), minimally active (600 to 3.000 Mets.min.week⁻¹) and HEPA active (>3.000 Mets.min.weeks⁻¹). Socio-ecological data were collected with the same online questionnaire, through individual interpersonal and environmental correlates. The last two determinants of socio-ecological model adapted to PA (regional and global) were not measured, as they corresponded to the context of the covid-19 pandemic with the lockdown and social distancing measures, and the re-organization of the educational system in France (Table 1).

Table I. *Socio-ecological characteristics of participants*

Socio-ecological determinants	Category	Frequency N (%)
Total		644 (100)
Individual		
<i>Gender</i>	Girls	418 (65)
	Boys	226 (35)
<i>PA profile</i>	HEPA active	236 (36.7)
	Minimally active	338 (52.5)
	Inactive	70 (10.8)
Interpersonal		
<i>PE monitoring</i>	No continuity	138 (21.4)
	Continuity not executed	262 (40.7)
	Continuity executed	244 (37.9)
<i>Sport social support</i>	Yes	455 (70.7)
	No	189 (29.3)
Environmental		
<i>Socio-economic status</i>	LSES	337 (52.3)
	HSES	397 (47.7)
<i>Localization</i>	Urban	319 (49.5)
	Rural	325 (50.5)
<i>Housing</i>	Home	422 (65.5)
	Flat	222 (34.5)
<i>Garden</i>	Yes	440 (68.3)
	No	204 (31.7)
<i>Sports equipment at home</i>	Yes	457 (71)
	No	187 (29)

Notes. PE: Physical Education; LSES: Low Socio-Economic Status; HSES: High Socio-Economic Status


Statistical analysis


Statistical analyses were conducted with the free R software (version 4.10). We used the following packages: car, heplots, lm.beta, lsr, outliers, psych, QuantPsyc, rstatix. All quantitative variables and residuals were tested for normality, homoscedasticity and interdependence of the residuals (Shapiro-Wilk; Jarque Bera; Bptest; Durbin Watson test). We performed a series of Wilcoxon signed rank test with continuity correction to measure the evolution of PA between before and during lockdown in each intensity. Feature socio-ecological variables included in PA evolution was determined by Boruta algorithm. Boruta is a wrapper approach developed around the random forest algorithm (Breiman, 2001) used for feature selection. Boruta calculated feature importance scores based on z-scores of every input predictor concerning the shadow attribute randomly assigned (Kursa & Rudnicki, 2010). A variable is considered relevant for classification if its feature importance score is greater than that of the best shadow feature (greater than 'shadowmax'). Any variable that cannot satisfy this condition is reported as irrelevant (smaller than 'shadowmax') and is discarded (n=5 for model 1- LMVPA; n=3 for model 2- LPA; n=4 for model 3- MVPA). Items with the highest feature importance scores (imp) are considered the best predictors of the dependent variable. The Boruta algorithm calculates average feature importance values based on 100 iterations of the random forest algorithm to increase the robustness of feature importance results (Kursa & Rudnicki, 2010). Statistical level of confidence was set at $p < .05$.

Results.

The results of the series of comparisons of medians by Wilcoxon sign rank test (Table 2) showed significant decreases in LMVPA (-231 Mets.min.week⁻¹; $p < .001$) and LPA (-480 Mets.min.week⁻¹, $p < .001$). MVPA has remained significantly stable during the lockdown (+0 Mets.min.week⁻¹, $p < .05$). However, this result was not homogeneous by PA level, as moderate PA (MPA) increased significantly (+84 Mets.min.week⁻¹, $p < .001$) while vigorous PA (VPA) decreased significantly (-180 Mets.min.week⁻¹, $p < .001$).

Table II. *Evolution of self-reported physical activity between before and during lockdown*

	LMVPA	LPA	MVPA	MPA	VPA
Before	2333	960	906	396	400
lockdown	[1319; 3742]	[360; 2160]	[470; 1553]	[66; 825]	[180; 720]
During	1585	400	1070	720	99
lockdown	[720; 2727]	[160; 800]	[294; 2100]	[0; 1600]	[0; 462]
	-231*	-480*	0*	+84*	-180*
	[-1407; 0]	[-1680; 120.00]	[-600; 938]	[-331; 1052]	[-527; 6]

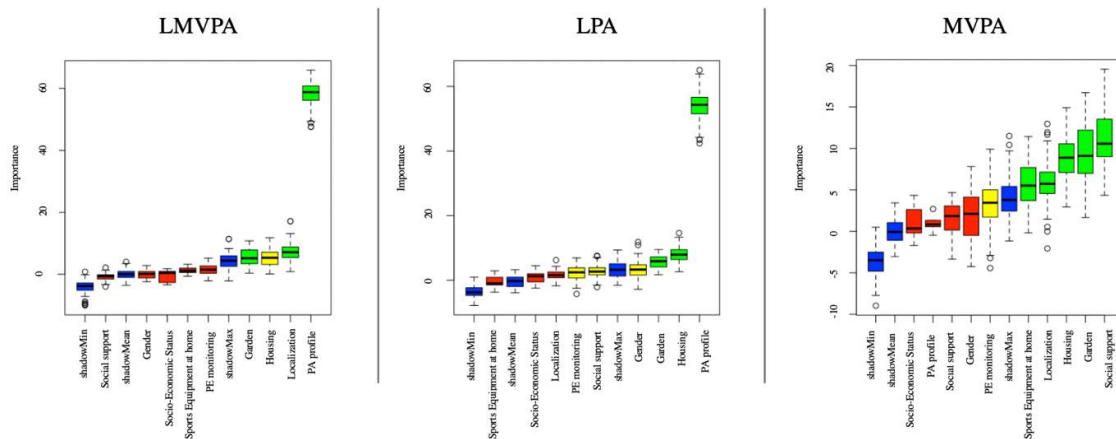
Notes. Data were presented in median [Q1; Q3] in Mets.min.week⁻¹. *: $p < 0.05$; : Evolution between before and during lockdown.

The feature importance scores generated by the Boruta algorithm (Table 3, Figure 1) demonstrated that all three determinants of the socio-ecological model of PA engagement are confirmed as important predictors of PA. The three determinants are confirmed for LPA (PA profile, sport social support at home, housing, and garden) and MVPA (gender, PE monitoring, localization, housing, garden, and sports equipment at home). For

LMVPA, only individual (PA profile) and environmental (localization and garden) determinants are considered as important. More particularly, the median feature importance score suggested that the individual determinants are the most important for LMVPA (PA profile: 58.8) and LPA (54.29), while environmental determinants (garden: 10.42; housing: 9.86) have a most impact for MVPA' engagement.

Table III. Variable importance information obtained with Boruta algorithm according to the evolution of PA behaviour between before and during lockdown

	Mean Imp	Median Imp	Min Imp	Max Imp	Norm Hits	Decision
<i>LMVPA</i>						
<i>Individual</i>						
Gender	0.01	0.01	-2.4	2.82	0.01	Rejected
PA profile	58	58.8	47.56	65.9	1	Confirmed
<i>Interpersonal</i>						
PE monitoring	1.31	1.49	-2.12	5.22	0.01	Rejected
Sport social support	-0.77	-0.63	-4	2.15	0.01	Rejected
<i>Environmental</i>						
Socio-economic status	-0.43	.44	-3.41	1.83	0	Rejected
Localization	7.26	7.11	0.88	17.14	0.82	Confirmed
Housing	5.26	5.33	0.12	11.8	0.63	Rejected
Garden	5.47	5.17	0.39	10.8	0.67	Confirmed
Sports equipment at home	1.23	1.13	-0.64	3.26	0.01	Rejected
<i>LPA</i>						
<i>Individual</i>						
Gender	3.19	3.32	-2.8	11.82	0.5	Rejected
PA profile	53.73	54.29	42.37	65.02	1	Confirmed
<i>Interpersonal</i>						
PE monitoring	2.3	2.47	-4.23	6.92	0.37	Rejected
Sport social support	2.89	2.7	-2.13	7.6	0.44	Confirmed
<i>Environmental</i>						
Socio-economic status	.85	1.26	-2.42	4.5	0.01	Rejected
Localization	1.76	1.58	-1.7	6.2	0.06	Rejected
Housing	7.91	7.93	2.66	14.63	0.94	Confirmed
Garden	5.7	5.89	1.72	9.51	0.86	Confirmed
Sports equipment at home	-0.5	-0.96	-3.7	2.94	0	Rejected
<i>MVPA</i>						
<i>Individual</i>						
Gender	3.48	3.65	-7.02	10.08	0.41	Confirmed
PA profile	1.73	1.9	-2.46	6.79	0.06	Rejected
<i>Interpersonal</i>						
PE monitoring	4.13	4.41	-5.55	10.08	0.53	Confirmed
Sport social support	1.35	0.95	-0.24	4.53	0.01	Rejected
<i>Environmental</i>						
Socio-economic status	1.90	1.79	-2.48	5.88	0.11	Rejected
Localization	6.17	5.98	1.98	11.74	0.73	Confirmed
Housing	7.91	7.93	2.66	14.63	0.94	Confirmed
Garden	9.68	10.42	2.76	16.11	0.95	Confirmed
Sports equipment at home	8	7.59	2.43	20.62	0.89	Confirmed



Notes. Blue boxplots correspond to minimal (shadowMin), average (shadowMean), and maximum (shadowMax) z-score of a shadow attribute. Red and green boxplots represent z-scores of respectively rejected and confirmed determinants. The yellow boxplots are tentative, that means the algorithm was not able to arrive to a conclusion about their importance.

Figure I. Boruta results plot for LMVPA, LPA, and MVPA.

Discussion.

The objective of the present study was to measure the evolution of each intensity of PA for adolescents during the transition to a lockdown lifestyle and to investigate the protective or inhibitor effect of each socio-ecological determinants.

Our results showed a reorganization of adolescents' PA patterns during the lockdown. Each PA's intensity observed a different variation and was impacted simultaneously by the determinants of socio-ecological models. In accordance with other countries, our results showed a significant decrease in the overall amount of PA (Rodríguez-Larrad et al., 2021). More particularly, the decrease of LPA may be explained by the absence of PA's practices related to active travel during lockdown and more broadly, by the loss of PA opportunities in this context (Wilke et al., 2021). On one hand, lockdown period has considerably increased the amount of leisure time that appears to be one of the barriers to PA among adolescents in ordinary times (Duffey et al., 2021). On the other hand, this increase in free time at home may have led to an increase in screen-based leisure activities widely enjoyed by young people and caused an increase in sedentary lifestyles (Arundell et al. 2015; Schmidt et al., 2020). It appears that the entry into lockdown significantly disrupted all the social and physical interactions that could impact the quantity and intensity of PA positively or negatively. Conversely, our results showed a French' adolescents particularity with an increase of MVPA compared to other country (Faulkner et al., 2021) and population (Fernández-García et al., 2021; Stockwell et al., 2021). These results could be explained by a French culture particularity (Van De Velde, 2015), in line with Piggini's definition of PA where the cultural dimension is essential (Piggini, 2020). These results could also be explained by adolescents' attraction to independent sports, encouraging by the lockdown due to the reduction of interaction and limiting the impact of the closure of clubs and other collective sports facilities (Crouette et al., 2019).

Results confirmed the importance of the socio-ecological perspectives to investigate PA's engagement (Bauman et al., 2012; Martins et al., 2021), especially during a period of lifestyle transition. Adapted to the particularities of adolescents, the identification of socio-ecological variables such as initial PA profile, location, or educational follow-up echoes the findings of studies on the effect of the pandemic on other population. They show respectively the influence of psychological, environmental (Teran-Escobar et al., 2021) and interpersonal determinants (Carter & Alexander, 2021), but without considering the relative importance of each layer, yet essential in the use of the ecological model (Tudge et al., 2009). Concerning the LMVPA evolution, the lack of intrapersonal determinant of the ecological model leads us to encourage further studies targeting the interactions between individuals in the PA engagement process. For example, the lack of knowledge about PE monitoring during covid-19 (interpersonal determinant) seems to be a barrier to engagement in LMVPA still insufficiently studied (Varea et al., 2022), while physical education is an important time for PA promotion (Lonsdale et al., 2013). These results, with the interaction of ecological model's determinants ((Bronfenbrenner & Morris, 2006) encourage to rethink PA health education strategies to prevent further lifestyle critical transition.

The strengths of this study consisted in the use of a longitudinal follow-up of French adolescents using a questionnaire with an adequate degree of reliability ($r_w = .74$, Sember et al., 2020). However, as lockdown was not predictable, it was necessary to ask participants to complete the questionnaire retrospectively for the week preceding the lockdown. The population was selected through a network of contacts including the SNEP and was not randomized and controlled, which may constitute a sampling bias. Another limitation appeared in the non-exhaustiveness of the socio-ecological determinants measured, although again it is important to balance the intrusion into participants' lives by implementing such large-scale measurement instruments. This study, although inspired by Bronfenbrenner ecological model (Bronfenbrenner & Morris, 2006), did not explore all the determinants since we selected those that seemed to be the most representative of the adolescents' lifestyle during the first lockdown (Génin et al., 2021).

Conclusions.

This study confirmed pre-existing studies on PA decrease during the lockdown against covid-19 and contribute to new knowledges with the consideration of the interactions of socio-ecological variables to explain the changes of all PA intensities. The interactions of variables relating to initial PA levels (individual), distance educational follow-up (interpersonal) and living locations (environment) are protective against PA drop out. These results strengthen the need to perceive PA as a complex energy expenditure that depends on a set of interacting variables. The use of non-linear statistical models is recommended for a better understanding of engagement processes. Indeed, persistent engagement in PA requires the ability to identify facilitating lifestyle barriers. Our results supported the idea that the socio-ecological framework can highlight the relative importance (protective, null or inhibitive barriers) of the interaction of each determinant (individual, interpersonal and environmental) on PA's intensities of adolescents. Thus, these results suggest perspectives in the promotion of a physically active lifestyle since the consideration of socio-ecological model is necessary to capture the complexity of PA's engagement. Further studies would be needed to measure the evolution of PA according to the socio-ecological profiles of adolescents to identify resilient patterns.

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Conflicts of interest. The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors contribution. All authors read and approved the final version of the manuscript.

References.

- Alcántara-Porcuna, V., Sánchez-López, M., Martínez-Vizcaíno, V., Martínez-Andrés, M., Ruiz-Hermosa, A., & Rodríguez-Martín, B. (2021). Parents' Perceptions on Barriers and Facilitators of Physical Activity among Schoolchildren: A Qualitative Study. *International Journal of Environmental Research and Public Health*, 18(6), Art. 6. <https://doi.org/10.3390/ijerph18063086>
- Ammar, A., Brach, M., Trabelsi, K., Chtourou, H., Boukhris, O., Masmoudi, L., Bouaziz, B., Bentlage, E., How, D., Ahmed, M., Müller, P., Müller, N., Aloui, A., Hammouda, O., Paineiras-Domingos, L. L., Braakman-Jansen, A., Wrede, C., Bastoni, S., Pernambuco, C. S., ... On Behalf of the ECLB-COVID19 Consortium. (2020). Effects of COVID-19 Home Confinement on Eating Behaviour and Physical Activity: Results of the ECLB-COVID19 International Online Survey. *Nutrients*, 12(6), Art. 6. <https://doi.org/10.3390/nu12061583>
- Arundell, L., Fletcher, E., Salmon, J., Veitch, J., & Hinkley, T. (2016). The correlates of after-school sedentary behavior among children aged 5–18 years: A systematic review. *BMC Public Health*, 16(1), 58. <https://doi.org/10.1186/s12889-015-2659-4>
- Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J., & Martin, B. W. (2012). Correlates of physical activity: Why are some people physically active and others not? *The Lancet*, 380(9838), 258-271. [https://doi.org/10.1016/S0140-6736\(12\)60735-1](https://doi.org/10.1016/S0140-6736(12)60735-1)
- Boberska, M., Szczuka, Z., Kruk, M., Knoll, N., Keller, J., Hohl, D. H., & Luszczynska, A. (2018). Sedentary behaviours and health-related quality of life. A systematic review and meta-analysis. *Health Psychology Review*, 12(2), 195-210. <https://doi.org/10.1080/17437199.2017.1396191>
- Breiman, L. (2001). Random Forests. *Machine Learning*, 45(1), 5-32. <https://doi.org/10.1023/A:1010933404324>
- Bronfenbrenner, U., & Morris, P. A. (2006). The Bioecological Model of Human Development. In *Handbook of child psychology: Theoretical models of human development, Vol. 1, 6th ed* (p. 793-828). John Wiley & Sons Inc.
- Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., ... Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, 54(24), 1451-1462. <https://doi.org/10.1136/bjsports-2020-102955>
- Carter, A., & Alexander, A. C. (2021). « It's a Whole Different Atmosphere »: A Qualitative Examination of Social Support as a Facilitator of Exercise During the COVID-19 Pandemic. *Health Promotion Practice*, 22(5), 622-630. <https://doi.org/10.1177/15248399211013005>
- Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports (Washington, D.C.: 1974)*, 100(2), 126-131.
- Castañeda-Babarro, A., Arbillaga-Etxarri, A., Gutiérrez-Santamaría, B., & Coca, A. (2020). Physical Activity Change during COVID-19 Confinement. *International Journal of Environmental Research and Public Health*, 17(18), Art. 18. <https://doi.org/10.3390/ijerph17186878>
- Cheval, B., Sivaramakrishnan, H., Maltagliati, S., Fessler, L., Forestier, C., Sarrazin, P., Orsholits, D., Chalabaev, A., Sander, D., Ntoumanis, N., & Boisgontier, M. P. (2021). Relationships between changes in self-reported physical activity, sedentary behaviour and health during the coronavirus (COVID-19) pandemic in France and Switzerland. *Journal of Sports Sciences*, 39(6), 699-704. <https://doi.org/10.1080/02640414.2020.1841396>
- Croutte, P., Müller, J., & Hoibian, S. (2019). *National Barometer of Sport Practices 2018 (Crédoc)* (INJEPR-2019/01; p. 90). <https://injep.fr/publication/barometre-national-des-pratiques-sportives-2018/> [in French]
- Derigny, T., Schnitzler, C., Gandrieux, J., & Potdevin, F. (2022). Resilience of adolescents in physical activity during the covid-19 pandemic: A preliminary case study in France. *Physical Activity Review*, 10(1), 86-97. <https://doi.org/10.16926/rp.2020.12.10>
- Duffey, K., Barbosa, A., Whiting, S., Mendes, R., Yordi Aguirre, I., Tcymbal, A., Abu-Omar, K., Gelius, P., & Breda, J. (2021). Barriers and Facilitators of Physical Activity Participation in Adolescent Girls: A Systematic Review of Systematic Reviews. *Frontiers in Public Health*, 9. <https://www.frontiersin.org/articles/10.3389/fpubh.2021.743935>

- Ekelund, U., Steene-Johannessen, J., Brown, W. J., Fagerland, M. W., Owen, N., Powell, K. E., Bauman, A., & Lee, I.-M. (2016). Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *The Lancet*, 388(10051), 1302-1310. [https://doi.org/10.1016/S0140-6736\(16\)30370-1](https://doi.org/10.1016/S0140-6736(16)30370-1)
- Faulkner, J., O'Brien, W. J., McGrane, B., Wadsworth, D., Batten, J., Askew, C. D., Badenhorst, C., Byrd, E., Coulter, M., Draper, N., Elliot, C., Fryer, S., Hamlin, M. J., Jakeman, J., Mackintosh, K. A., McNarry, M. A., Mitchelmore, A., Murphy, J., Ryan-Stewart, H., ... Lambrick, D. (2021). Physical activity, mental health and well-being of adults during initial COVID-19 containment strategies: A multi-country cross-sectional analysis. *Journal of Science and Medicine in Sport*, 24(4), 320-326. <https://doi.org/10.1016/j.jsams.2020.11.016>
- Fernández-García, Á. I., Marin-Puyalto, J., Gómez-Cabello, A., Matute-Llorente, Á., Subías-Perié, J., Pérez-Gómez, J., Lozano-Berges, G., Mañas, A., Guadalupe-Grau, A., González-Gross, M., Ara, I., Casajús, J. A., & Vicente-Rodríguez, G. (2021). Impact of the Home Confinement Related to COVID-19 on the Device-Assessed Physical Activity and Sedentary Patterns of Spanish Older Adults. *BioMed Research International*, 2021, e5528866. <https://doi.org/10.1155/2021/5528866>
- Genin, P. M., Lambert, C., Larras, B., Pereira, B., Toussaint, J.-F., Baker, J. S., Tremblay, A., Thivel, D., & Duclos, M. (2021). How Did the COVID-19 Confinement Period Affect Our Physical Activity Level and Sedentary Behaviors? Methodology and First Results From the French National ONAPS Survey. *Journal of Physical Activity and Health*, 18(3), 296-303. <https://doi.org/10.1123/jpah.2020-0449>
- Gobbi, E., Maltagliati, S., Sarrazin, P., di Fronso, S., Colangelo, A., Cheval, B., Escrivá-Boulley, G., Tessier, D., Demirhan, G., Erturan, G., Yüksel, Y., Papaioannou, A., Bertollo, M., & Carraro, A. (2020). Promoting Physical Activity during School Closures Imposed by the First Wave of the COVID-19 Pandemic: Physical Education Teachers' Behaviors in France, Italy and Turkey. *International Journal of Environmental Research and Public Health*, 17(24), Art. 24. <https://doi.org/10.3390/ijerph17249431>
- Hargreaves, E. A., Lee, C., Jenkins, M., Calverley, J. R., Hodge, K., & Houge Mackenzie, S. (2021). Changes in Physical Activity Pre-, During and Post-lockdown COVID-19 Restrictions in New Zealand and the Explanatory Role of Daily Hassles. *Frontiers in Psychology*, 12. <https://www.frontiersin.org/articles/10.3389/fpsyg.2021.642954>
- Kalman, M., Inchley, J., Sigmundova, D., Iannotti, R. J., Tynjala, J. A., Hamrik, Z., Haug, E., & Bucksch, J. (2015). Secular trends in moderate-to-vigorous physical activity in 32 countries from 2002 to 2010: A cross-national perspective. *The European Journal of Public Health*, 25(suppl 2), 37-40. <https://doi.org/10.1093/eurpub/ckv024>
- Kursa, M. B., & Rudnicki, W. R. (2010). Feature Selection with the Boruta Package. *Journal of Statistical Software*, 36(11). <https://doi.org/10.18637/jss.v036.i11>
- Lonsdale, C., Rosenkranz, R. R., Peralta, L. R., Bennie, A., Fahey, P., & Lubans, D. R. (2013). A systematic review and meta-analysis of interventions designed to increase moderate-to-vigorous physical activity in school physical education lessons. *Preventive Medicine*, 56(2), 152-161. <https://doi.org/10.1016/j.ypmed.2012.12.004>
- López-Valenciano, A., Suárez-Iglesias, D., Sanchez-Lastra, M. A., & Ayán, C. (2021). Impact of COVID-19 Pandemic on University Students' Physical Activity Levels: An Early Systematic Review. *Frontiers in Psychology*, 11. <https://www.frontiersin.org/articles/10.3389/fpsyg.2020.624567>
- Martín-Rodríguez, A., Tornero-Aguilera, J. F., López-Pérez, P. J., & Clemente-Suárez, V. J. (2021). Gender Differences in Nutritional, Odontological and Psychological Patterns of Adolescent Students during COVID-19 Pandemic. *Applied Sciences*, 11(18), 8499. <https://doi.org/10.3390/app11188499>
- Martins, J., Costa, J., Sarmiento, H., Marques, A., Farias, C., Onofre, M., & Valeiro, M. G. (2021). Adolescents' Perspectives on the Barriers and Facilitators of Physical Activity: An Updated Systematic Review of Qualitative Studies. *International Journal of Environmental Research and Public Health*, 18(9), 4954. <https://doi.org/10.3390/ijerph18094954>
- McDougall, C. W., Brown, C., Thomson, C., Hanley, N., Tully, M. A., Quilliam, R. S., Bartie, P. J., Gibson, L., & Oliver, D. M. (2021). From one pandemic to another: Emerging lessons from COVID-19 for tackling physical inactivity in cities. *Cities & Health*, 5(sup1), S181-S184. <https://doi.org/10.1080/23748834.2020.1785165>
- Piggin, J. (2020). What Is Physical Activity? A Holistic Definition for Teachers, Researchers and Policy Makers. *Frontiers in Sports and Active Living*, 2. <https://www.frontiersin.org/articles/10.3389/fspor.2020.00072>
- Poitras, V. J., Gray, C. E., Borghese, M. M., Carson, V., Chaput, J.-P., Janssen, I., Katzmarzyk, P. T., Pate, R. R., Connor Gorber, S., Kho, M. E., Sampson, M., & Tremblay, M. S. (2016). Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Applied Physiology, Nutrition, and Metabolism*, 41(6 (Suppl. 3)), S197-S239. <https://doi.org/10.1139/apnm-2015-0663>
- Potdevin, F., Llena, C., Gandrieau, J., Dieu, O., Derigny, T., Porrovecchio, A., & Schnitzler, C. (2020). Physical Education teacher 2.0 or how PE teachers reconfigured their mission as promoters of physical activity

- and health during lockdown. *Recherches & éducatons*, HS. <https://doi.org/10.4000/rechercheseducations.10317> [in French]
- Rodríguez-Larrad, A., Mañas, A., Labayen, I., González-Gross, M., Espin, A., Aznar, S., Serrano-Sánchez, J. A., Vera-García, F. J., González-Lamuño, D., Ara, I., Carrasco-Páez, L., Castro-Piñero, J., Gómez-Cabrera, M. C., Márquez, S., Tur, J. A., Gusi, N., Benito, P. J., Moliner-Urdiales, D., Ruiz, J. R., ... Irazusta, J. (2021). Impact of COVID-19 Confinement on Physical Activity and Sedentary Behaviour in Spanish University Students: Role of Gender. *International Journal of Environmental Research and Public Health*, 18(2), Art. 2. <https://doi.org/10.3390/ijerph18020369>
- Schmidt, S. C. E., Anedda, B., Burchartz, A., Eichsteller, A., Kolb, S., Nigg, C., Niessner, C., Oriwol, D., Worth, A., & Woll, A. (2020). Physical activity and screen time of children and adolescents before and during the COVID-19 lockdown in Germany: A natural experiment. *Scientific Reports*, 10(1), Art. 1. <https://doi.org/10.1038/s41598-020-78438-4>
- Sember, V., Meh, K., Sorić, M., Starc, G., Rocha, P., & Jurak, G. (2020). Validity and Reliability of International Physical Activity Questionnaires for Adults across EU Countries: Systematic Review and Meta Analysis. *International Journal of Environmental Research and Public Health*, 17(19), Art. 19. <https://doi.org/10.3390/ijerph17197161>
- Stockwell, S., Trott, M., Tully, M., Shin, J., Barnett, Y., Butler, L., McDermott, D., Schuch, F., & Smith, L. (2021). Changes in physical activity and sedentary behaviours from before to during the COVID-19 pandemic lockdown: A systematic review. *BMJ Open Sport & Exercise Medicine*, 7(1), e000960. <https://doi.org/10.1136/bmjsem-2020-000960>
- Teran-Escobar, C., Forestier, C., Ginoux, C., Isoard-Gauthier, S., Sarrazin, P., Clavel, A., & Chalabaev, A. (2021). Individual, Sociodemographic, and Environmental Factors Related to Physical Activity During the Spring 2020 COVID-19 Lockdown. *Frontiers in Psychology*, 12. <https://www.frontiersin.org/articles/10.3389/fpsyg.2021.643109>
- Tudge, J. R. H., Mokra, I., Hatfield, B. E., & Karnik, R. B. (2009). Uses and Misuses of Bronfenbrenner's Bioecological Theory of Human Development. *Journal of Family Theory & Review*, 1(4), 198-210. <https://doi.org/10.1111/j.1756-2589.2009.00026.x>
- Van De Velde, C. (2015). *Sociology of the ages of life* (Armand Colin). <https://www.dunod.com/sciences-humaines-et-sociales/sociologie-ages-vie> [in French]
- Varea, V., & González-Calvo, G. (2021). Touchless classes and absent bodies: Teaching physical education in times of Covid-19. *Sport, Education and Society*, 26(8), 831-845. <https://doi.org/10.1080/13573322.2020.1791814>
- Varea, V., González-Calvo, G., & García-Monge, A. (2022). Exploring the changes of physical education in the age of Covid-19. *Physical Education and Sport Pedagogy*, 27(1), 32-42. <https://doi.org/10.1080/17408989.2020.1861233>
- Varma, V. R., Dey, D., Leroux, A., Di, J., Urbaneck, J., Xiao, L., & Zipunnikov, V. (2017). Re-evaluating the effect of age on physical activity over the lifespan. *Preventive Medicine*, 101, 102-108. <https://doi.org/10.1016/j.ypmed.2017.05.030>
- Varma, V. R., Tan, E. J., Wang, T., Xue, Q.-L., Fried, L. P., Seplaki, C. L., King, A. C., Seeman, T. E., Rebok, G. W., & Carlson, M. C. (2014). Low-Intensity Walking Activity Is Associated With Better Health. *Journal of Applied Gerontology*, 33(7), 870-887. <https://doi.org/10.1177/0733464813512896>
- Wilke, J., Mohr, L., Tenforde, A. S., Edouard, P., Fossati, C., González-Gross, M., Sánchez Ramírez, C., Laiño, F., Tan, B., Pillay, J. D., Pigozzi, F., Jimenez-Pavon, D., Novak, B., Jaunig, J., Zhang, M., van Poppel, M., Heidt, C., Willwacher, S., Yuki, G., ... Hollander, K. (2021). A Pandemic within the Pandemic? Physical Activity Levels Substantially Decreased in Countries Affected by COVID-19. *International Journal of Environmental Research and Public Health*, 18(5), Art. 5. <https://doi.org/10.3390/ijerph18052235>