**Abstract**

**Objective:** The present study aimed to explore among French children: 1) the impact of a two-month lockdown during the COVID-19 pandemic on the symptoms of ADHD, ODD and anxiety; and 2) to what extent behavioural regulation skills at study start moderated the expression of these symptoms. **Method:** The study involved 235 children aged 6 to 13 (Mean = 9.72; SD = 1.8; Sex-Ratio = 1.37) with ADHD treated with methylphenidate, recruited via the association “HyperSupers – TDAH France”. The symptom severity of ADHD, ODD and anxiety was investigated with validated scales one and two months after the beginning of lockdown, and one month after its end. **Results:** A significant increase in scores for all scales was observed between one and two months after the beginning of lockdown. Among children with high scores on the Behaviour Regulation Index (BRI), mean scores one month after the end of lockdown remained significantly higher than one month after the beginning of lockdown, while among children with lower BRI scores, mean scores one month after the end of lockdown either returned to or were lower than levels observed one month after the beginning of lockdown. **Conclusion:** Overall symptoms of ADHD, ODD and anxiety among French children worsened during the lockdown despite ongoing pharmacologic treatment for ADHD, but initial behavioural regulation skills significantly moderated both symptom severity and persistence.

***Keywords:*** ADHD, ODD, anxiety, lockdown, COVID-19, behavioural regulation, emotional regulation, sleep

**Key Practitioner Message**

* The complete lockdown during the COVID-19 pandemic in France led to an upheaval in children's habits.
* This study aimed to assess the impact of lockdown among French children with ADHD in order to gain insight on how to prevent symptomatic deterioration and to support children facing similar life events.
* This study is the first to demonstrate the influence of initial behavioural regulation difficulties on the changes in ADHD symptoms and associated disorders during lockdown.
* Given the results of this study, the initial level of behavioural regulation difficulties appears to be a useful domain to assess in order to identify children with ADHD who are most at risk of symptomatic deterioration and/or who need extra support during challenging times such as the current COVID-19 pandemic.

**INTRODUCTION**

**Attention-Deficit-Hyperactivity Disorder (ADHD)**

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder, often persisting in adulthood, whose predominant symptoms appear before the age of 12 and are characterized by inattention and/or hyperactivity and impulsivity. Its diagnosis is based on the clinical observation of symptoms that appear in at least two life contexts (school, home, leisure, etc.) and are accompanied by functional impairment. The current classification distinguishes three presentations: predominantly inattentive, predominantly hyperactive-impulsive, and combined (DSM-5, APA, 2013). In 2015, the global prevalence of ADHD in children was estimated at 3.4% of the population (Polanczyk, Salum, Sugaya, Caye & Rohde, 2015) and 5% in 2018 (Sayal, Prasad, Daley, Ford & Coghill, 2018).

ADHD has a significant impact on daily functioning, with a substantial deterioration in quality of life, comparable to that measured in children with a chronic disease such as asthma or diabetes (Escobar et al., 2005; Danckaerts et al., 2010; Coghill & Hodgkins, 2016; Lee et al., 2016). Pharmacologic (Cortese, 2020) and non-pharmacologic (Daley et al., 2017) options are available for the treatment of ADHD across the lifespan (De Crescenzo, Cortese, Adamo & Janiri, 2016). Pharmacologic treatment has been shown to improve ADHD core symptoms as well as other important outcomes, e.g., the risk of unintentional injuries (Ruiz-Goikoetxea, 2017; Ghirardi, 2019), although no predictors of treatment response have been found so far (Purper-Ouakil et al., 2008).

ADHD is often associated with other (neuro)psychiatric comorbidities, including Oppositional Defiant Disorder (ODD) (25-80% of cases) (Franke et al., 2018) and anxiety disorders disorders (11-51%) (Bird, Gould & Staghezza, 1993; Busch et al., 2002; Bowen, Chavira, Bailey, Stein & Stein, 2008; Elia, Ambrosini & Berrettini, 2008; Larson et al., 2011; Bauermeister et al., 2013; Reale et al., 2017). Comorbidities also contribute to the deterioration in quality of life. For example, lower quality of life was observed by in children with both ADHD and oppositional disorder (Newcorn et al. 2005) or anxiety (Sciberras et al. 2014).

**Sleep in ADHD**

Sleep problems are present in 50% to 80% of children with ADHD, compared to 25% in the general paediatric population (van der Heijden, Stoffelsen, Popma & Swaab, 2018). Delays in melatonin release, higher bedtime resistance, sleep-onset and morning awakenings difficulties, increased nocturnal motor activity and sleep breathing disorders have been found in children and adolescents with ADHD (Cortese, Faraone, Konofal, & Lecendreux, 2009).

Sleep problems and ADHD seem to be intermingled: ADHD may disturb sleep and sleep disturbances may cause ADHD symptoms (Hvolby, 2015). Psychiatric comorbid disorders such as mood or conduct disorders could also be associated with sleep problems in paediatric ADHD (Konofal, Lecendreux & Cortese, 2010; Lycett, Mensah, Hiscock & Sciberras, 2014).

**Executive Functions and emotion regulation in ADHD**

Executive functions refer to high-level cognitive processes such as planning, decision-making, mental flexibility and adaptation to context (Miyake & Friedman, 2012). They are responsible for inhibition, and maintenance and transfer of attention and are anatomically located in the prefrontal cortex (Rubia, 2013). A sizeable portion of individuals with ADHD present with altered executive functions (Hart, Radua, Mataix & Rubia, 2013; McCarthy, Skokauskas & Frodl, 2014; Norman et al., 2016). While the impairment of these processes remains variable from case to case, it is often the cause of decreased performance on tasks of inhibition, working memory, resistance to interference, temporal perception, task change and reactivity (Coghill, Toplak, Rhodes & Adamo, 2018; Karr et al., 2018).

Executive dysfunctions may also be related to mood disorders and emotional dysregulation. Executive deficits have been demonstrated in children with Oppositional Defiant Disorder (Jiang, li, Du & Fan, 2016) and may underlie internalized disorders such as anxiety or depression (Oldehinkel, Hartman, Ferdinand, Verhulst & Ormel, 2007; Vasey et al., 2013; Hankin, Snyder & Gulley, 2015; Snyder, Miyake & Hankin, 2015).

Emotion is a transient affective reaction that occurs after an external or internal stimulation.

Emotion regulation is the ability to modify an emotional state and change one's behaviours at an end of adaption. It allows us to choose and pay attention to activated emotional stimuli, and to respond flexibly to these stimuli (McRae & Gross, 2020). The ability to regulate emotions is an important aspect of an individual's adaptive functioning. The neurobiological regulation of emotions is done through a top-down inhibitory process, from the cortical to the subcortical areas. When not suitable, the emotional response is inhibited by cognitive control. Emotions have a bottom-up regulatory role as they influence consequent behaviours (Purper-Ouakil & Franc, 2011).

Emotional regulation impairments are reported in paediatric populations with ADHD, in which it could convey comorbid mood or conduct disorders (Ryckaert, Kuntsi & Aherson, 2018; Faraone et al., 2019). Executive functions and attentional processes seem to be interrelated, and an impairment of emotion regulation could be the cause of the mood and behavioral disorders observed in children with ADHD. To date, the main hypotheses relate to neurological and genetic characteristics linking ADHD and emotional dysregulation. People with ADHD may have deficits in cortical control (Posner, Kass & Hulverson, 2014), and emotional dysregulation and ADHD were found to arise from correlated phenotypes (Asherson & Gurling, 2012; Merwood et al., 2014).

Given this involvement in emotional regulation and behavioural response, executive processes could condition children's adaptability to their environment and the changes that can occur in it. In young adults, executive performances were correlated with the effects of a stressful life event in a study by Shields et al. (2018).

**ADHD and Lockdown**

Health threats and associated lockdowns often lead to psychological repercussions, some of which have been highlighted during previous epidemics. For instance, in Australia during the 2007 equine influenza outbreak, populations of affected areas were more likely to experience symptoms of psychological distress (28% of individuals) than populations in areas with little or no disease (12% of individuals) (Taylor, Agho, Stevens & Raphael, 2008). Following a health threat episode, Sprang and Silman (2013) reported a four times higher level of post-traumatic stress scores among children and parents who were placed in quarantine than among those for whom quarantine was not necessary.

Several consequences of lockdown may influence ADHD symptoms and comorbidities. For example, situation-induced stress in parents could lead to an exacerbation of inattention, hyperactivity and opposition (Larsson, Sariaslan, Langstrom, D'Onofrio & Lichtenstein, 2014; Liu et al., 2018). Because the implementation of a physical activity program significantly improves functioning among children with ADHD (Hoza, Martin, Pirog & Shoulberg, 2016), the decrease in physical activity caused by sedentary lifestyles during lockdown could have a deleterious effect on ADHD symptoms and associated disorders. Furthermore, sedentary lifestyles are often accompanied by increased use of electronic devices, repeatedly suggested as a source of aggravation of inattention, impulsivity and hyperactivity in children with ADHD, especially with media containing violent content (Beyens, Valkenburg & Taylor Piotrowski, 2018). Night-time use of devices, combined with disruption of the biological clock due to changes in lifestyle routines, could also induce a deterioration in quality of sleep, which can exacerbate the severity of ADHD in children (Mulraney, Sciberras & Lecendreux, 2018).

However, the impact of prolonged lockdown on mood and behaviour in children with ADHD remains poorly investigated. While contextual dependence of ADHD symptoms has been demonstrated (Sonuga-Barke & Castellanos, 2007; Karalunas, Geurts & Konrad, 2014), few studies (Sciberras et al., 2020) and, to our knowledge, no study in France, has attempted to define the influence of lockdown associated with the current COVID-19 pandemic on ADHD symptoms.

**Objective of the study**

The present study aimed to explore among French children: 1) the impact of a two-month lockdown during the COVID-19 pandemic on the symptoms of ADHD, ODD and anxiety; and 2) to what extent behavioural regulation skills at study start moderated the expression of these symptoms.

**METHODS**

*Data collection and Population*

Data were collected longitudinally between April and July 2020. Children and families from the French ADHD association of patients “HyperSupers TDAH France” were contacted by email during lockdown. They were invited to answer online standardized questionnaires with three repeated measures at four-week intervals: one month after the start of lockdown, two months after the start of lockdown and one month after the end of lockdown.

Participants were eligible if they met DSM-5 criteria for ADHD diagnosed by a physician, were using methylphenidate without any interruption or dose reduction during the study period, and were aged 6 to 13 years. Patients on antidepressant or anxiolytic therapy, as well as patients with Autism Spectrum Disorder, were excluded.

Behavioural regulation difficulties were measured at study start with the Behavioural Regulation Index (BRI) of the Brief Executive Function Rating Scale using parent-rated version (Gioia et al., 2000; translated et validated in French by Roy, Fournet, Roulin & Le Gall, 2014), which assesses difficulties of inhibition, flexibility and emotional control.

The parent-rated ODD questionnaire developed by Boudreault at the CHU de Québec (2003), was used to measure the changes in oppositional behaviours during lockdown (score range 0–33).

The Revised Childhood Anxiety Scale for Manifest Anxiety (RCMAS) was developed by Reynolds and Richmond in 1999 and validated in French by Turgeon and Chartrand in 2003 (score range 0–37). The RCMAS was completed by the children to evaluate possible manifestations of anxiety during the study.

The parent-rated ADHD Symptom Rating Scale (ADHD-RS) for children aged 5 to 17 (DuPaul et al., 1998; validated in French by Mercier et al., 2016) measured ADHD profiles (predominantly inattentive [score range 0–27] or predominantly impulsive-hyperactive [score range 0–27]) and changes in ADHD symptoms of participants.

Questions on bedtime delay at the start of the study, number of outings per week, and treatment uptake were constructed for the purposes of the study and prefaced the standardized questionnaires.

The study was approved by the local ethics committee, based at the Robert-Debré hospital in Paris.

*Statistical analysis*

Raw data were collected anonymously and only complete data were processed. Statistical analyses were conducted with IBM SPSS Statistics 23.0 software.

Data were analysed using descriptive statistics.

Correlations between variables were established when relevant. Linear regressions and analysis of variance were performed to investigate interactions between variables. Inattention, impulsivity-hyperactivity, opposition and anxiety were dependent continuous variables and BRI level, bedtime delay level and time of measurement were independent categorical variables.

Statistical tests were applied after testing the assumption of normal distribution and homogeneity of variances. Greenhouse-Geisser correction was applied in case of non-verification of the sphericity hypothesis (Mauchly's test significant: p<0.05).

Changes in symptom scores over time were analysed using generalized linear mixed models for repeated measures, integrating four within-subject factors with three levels and one between-subject factor. The within-subject variables were scores of ODD, anxiety, inattention and impulsivity-hyperactivity, as well as the three-level measurement of time: one month after lockdown beginning, two months after lockdown beginning and one month after lockdown end. The between-subject variable was BRI score split into four categorical levels (quartiles). Separating the BRI variable into quartiles enabled different patterns of symptom changes to be identified in relation to behavioural regulation difficulties present at study start.

**Results**

*Characteristics of participating children at study start*

Of 1000 families contacted, 235 children met the criteria for inclusion in the study. Characteristics of the participating children are shown in Table 1. The study involved 235 children aged 6 to 13 (Mean = 9.7; SD = 1.8; Male to Female Ratio = 1.37). Mean BRI score (70.4), measured at the beginning of the study, was two standard deviations above the general population (mean = 50; standard deviation = 10) (Roy, Fournet, Roulin & Le Gall, 2014).

Participants were divided into four BRI levels as follows: BRI below 62 in Level 1, BRI between 62 and 71 in Level 2, BRI between 72 and 79 in Level 3, BRI above 79 in Level 4. This separation enabled statistical comparisons of equal groups of nearly 60 subjects each.

At study start, children with a predominantly impulsive-hyperactive ADHD profile had a higher index of behavioural regulation (Mean = 78.7; SD = 10.72) than those with a predominantly inattentive ADHD profile (Mean = 62.2; SD = 10.49).

*Correlations between ODD, ADHD, and anxiety symptom scores and BRI*

There was a significant positive correlation between the BRI score and scores of ODD (r = 0.840; p<0.01), anxiety (r = 0.636; p<0.01), inattention (r = 0.664; p<0.01) and impulsivity-hyperactivity (r = 0.784; p<0.01)

*Symptoms during and after lockdown according to BRI level*

*Between-subject effects*

BRI was an explanatory factor for the scores of ODD, anxiety, inattention and impulsivity-hyperactivity (p<0.05). BRI explained 67.8% of the variability in ODD scores, 40.6% of the variability of anxiety scores, 44.1% of the variability of inattention scores and 59.7% of the variability of impulsivity-hyperactivity scores (Table 2).

*Within-subject effects*

There was a significant interaction between time of measurement and BRI (p<0.05) for ODD, anxiety, inattention and impulsivity-hyperactivity scores. With a 5% risk of error, BRI influenced the change in symptoms of opposition, anxiety, inattention and impulsivity during and after lockdown.

The interaction between time of measurement and BRI explained 28.7% of the variability of ODD score, 26.3% of the variability of RCMAS score, 31.9% of the variability of inattention score and 37.2% of the variability of impulsivity-hyperactivity score (Table 2).

Fig. 1 shows the differences in progression of symptom scores depending on BRI level. Patterns of change in opposition, anxiety, inattention and impulsivity-hyperactivity scores differed according to BRI level and generally followed a similar pattern over time:

* Among children with a BRI below 62, symptoms progressively decreased over time.
* Among children with a BRI between 62 and 71, symptoms increased from one month after the beginning of lockdown (T1) to two months after the beginning of lockdown (T2), but symptoms decreased at one month after the end of lockdown (T3) to a value lower than that observed at T1.
* Among children with a BRI between 72 and 79, all symptoms increased from T1 to T2 and then, for anxiety and inattention symptoms, decreased at T3 to a similar value to that recorded at T1, and for oppositional and impulsivity-hyperactivity symptoms, decreased at T3 but remained at a higher value than that recorded at T1.
* Among children with a BRI above 79, symptoms increased during lockdown from T1 to T2 and then decreased at T3 but remained at a higher value than that recorded at T1.

*Symptoms and bedtime delay*

An alternate hypothesis concerning the association between lockdown and exacerbation of ADHD symptoms might involve lockdown-associated changes in sleep rhythms, which, in turn, could have negative repercussions on ADHD symptoms and associated disorders.

Of 235 participants, 140 had delayed their bedtime by up to one hour, 49 by up to two hours, and 46 had no bedtime delay.

An increase in the mean scores of opposition, anxiety, inattention and impulsivity scales with an increase in the number of hours of bedtime delay was observed (Figure 2), showing the greatest symptom burden among subjects with the greatest bedtime delay. However, symptoms increased from one to two months after the beginning of lockdown and decreased after the end of lockdown, irrespective of the level of bedtime delay (Figure 2; within-subject effects in the generalized linear model were insignificant).

**Discussion**

The objective of this study was to determine the impact of a prolonged lockdown on the symptoms of ADHD and associated disorders in children aged 6 to 13 years, and the influence of initial behavioural regulation level on the expression of these symptoms.

Consistent with previous studies suggesting an association between emotional dysregulation and ADHD (Brotman et al., 2006; Anastopoulos et al., 2011; Sjöwall, Roth, Lindqvist & Thorell, 2013; Villemonteix, Purper-Ouakil & Romo, 2015; van Stralen, 2016), the Behavioural Regulation Index mean score was higher in the participants of this study than in the general population. The novel finding from this study was that the distribution of ADHD subtypes varied according to the BRI leve, with the most significant behavioural regulation difficulties occurring in predominantly impulsive-hyperactive children, and the least in predominantly inattentive children. Children with a combined profile had intermediate scores but were too few in number to draw firm conclusioins.

With two measurements during lockdown and one a month after its end, this study is among the first ones to investigate the impact of lockdown on children with ADHD. The study by Zhang et al (2020) focused on evaluating the influence of health crises on the behavioural manifestations of ADHD and anxiety using a single measurement time point, and showed an exacerbation of ADHD symptoms and a deterioration of mood.

Another study by Sciberras et al. (2020) aimed to investigate the impact of the COVID-19 pandemic on children with ADHD in Australia using the CoRonavIruS Health Impact Survey (CRISIS) to assess changes in physical health, media use and mental health. Similar to the findings of the present study, these authors showed increased sadness, depressed mood and stress in children with ADHD and focused on the social impact of the pandemic. ADHD core symptoms as well as oppositional behaviours were not investigated, however, apart from one question on distractibility that appeared to be unchanged in Sciberras et al.’s population, unlike in the present study.

Here, the results suggest a combined exacerbation of symptoms of inattention, impulsivity and motor hyperactivity, oppositional behaviours and anxiety. These symptoms tended to increase between the first and second months after the beginning of lockdown and then decreased by one month after the end of lockdown. The largest decrease observed after release from lockdown occurred in the anxiety score.

However, we characterized these trends in relation to initial behavioural regulation difficulties, which represents an innovative contribution to this field of research. Because the Behavioural Regulation Index appears to be strongly correlated with scores on opposition, anxiety, inattention and impulsivity-hyperactivity, separating the sample into four equal groups according to BRI enables identification of differing trajectories of change in symptoms according to the initial level of behavioural disturbance. Thus, symptoms decreased continuously from one month after the beginning of lockdown to one month after its end among children with low levels of initial behavioural regulation difficulties. Among children with moderate to high levels of difficulty, symptoms increased until the second month of lockdown and then decreased after its end. Scores were lower than at the first measure when the BRI was between 62 and 71, higher when the BRI was above 79, and nearly equal in children with a BRI between 72 and 79.

Overall, the change in and persistence of impulsivity and motor hyperactivity symptoms were most strongly influenced by higher initial levels of the Behavioural Regulation Index.

These relationships between behavioural regulation difficulties and symptoms of ADHD and associated disorders seem to reflect a certain deficit in the ability of children with ADHD to adapt to an unusual and stressful situation over a long period of time. Regulation and manifestation of symptoms would depend here on the child’s capacity for inhibition, flexibility and emotional control.

While sample size issues make it difficult to interpret the data for participants with a BRI above 89 for whom a persistent increase in symptoms occurred, these findings suggest that a larger sample size would enable these trends to be further explored by dividing the participants into a larger number of subgroups. Such a distribution would also make it possible to investigate the differences observed among Level 3 participants (BRI between 72 and 79).

Observing the extremes, however, could prove to be difficult due to a ceiling effect on ADHD-RS scores. For those who reached the maximum score on the first measure, it is not possible to know whether the same score on the second or even third measure reflects a stabilization or an increase in symptoms.

Within a larger population, a greater number of factors could be considered when studying the impact of lockdown in children with ADHD, such as age, physical activity, time spent in front of screens, family environment, parents' attitudes towards the health crisis, school level, and children's cognitive profiles. It thus seems relevant to complement the analysis of profiles by taking into account the metacognitive dimension of executive functions, which includes abilities of initiation, working memory, planning, organization and control.

Although statistical analysis of the data did not show a significant link between bedtime delay and the patterns of trajectories of change in ADHD symptoms, anxiety and opposition during and after lockdown (a similar pattern was observed irrespective of bedtime delay level), a higher burden of symptoms was generally observed among those children with the highest level of bedtime delay. A more precise study on sleep and its influence on symptoms during periods of social stress seems justified, using specific investigation tools.

*Limitations*

An important limitation of this study concerns the lack of availability of baseline data before the onset of lockdown, the first measure having been taken one month after its beginning. For example, it is possible that had these data been available, children with the lowest initial BRI level might have shown a small increase in symptoms from before lockdown to one month after the start of lockdown.

It also important to consider the potential influence of the time of year on the progression of symptoms and the answers to questionnaires. Measurements taken during last weeks of the school term before the start of school holidays may have led some participants to lose interest in following the school curriculum at home, resulting in an apparent increase in ADHD symptoms and oppositional behaviour. The context of the last measurement timepoint, characterized by the beginning of the school holidays and the return of usual activities after a prolonged lockdown, should also be considered. Such a context may have reduced the ability of parents to observe their child’s symptoms or to accurately perceive the level of severity of these symptoms. In the same way, the observed changes in anxiety should be interpreted considering the context and environment, for example, negative media reports about the pandemic might increase anxiety symptoms, or the approach of the long school summer holiday might decrease these symptoms.

Another limitation of the study was the lack of a control group without ADHD to assess to what extent ADHD-like symptoms (distractibility, impulsivity) not meeting the threshold for diagnosis are exacerbated during lockdown and if BRI scores also predict exacerbation of symptoms in the general population.

**Conclusion**

This study is the first to demonstrate an influence of behavioural regulation abilities and difficulties on the changes in ADHD symptoms and associated disorders such as anxiety or opposition during lockdown, a health crisis marked by an upheaval in children's routines.

In view of the relationship found between BRI level and both inattention and impulsivity-hyperactivity scores obtained on the ADHD-RS, it might be appropriate to consider behavioural regulation difficulties as a useful domain to be assessed during the evaluation of ADHD, enabling these children to be better supported, especially during challenging times such as the current COVID-19 pandemic.

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We have no conflict of interest to declare.

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http://www.ncbi.nlm.nih.gov/pubmed/?term=konofal

He is granted of 88 International patents that were filed to protect the following inventions. This list of the contribution to science area includes patent applications that are pending as well as patents that have already been granted by the United States Patent and Trademark Office (USPTO), European Patent Office (EPO)…

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Dr Lecendreux is an author on journal articles, editorials, chapters and books in the area of ADHD and sleep and served as an Editorial Board Member for the Journal of Attention Disorders. Together with his colleagues he reported on the role of vigilance impairment in ADHD children and insisted on the role of iron deficiency in the pathophysiology of ADHD.

Dr Lecendreux is also involved in numerous activities including teaching medicine and education research on attention disorders at the Faculty of Medicine of Paris, France.

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