Evaluation of the effect of a serious game on the performance of daily routines by autistic and ADHD children

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Abstract

Objectives. Learning and performing new routines are difficult for children with neurodevelopmental disorders. Studies have shown that consistency in child reinforcement and parent support are effective. For example, digital solutions such as serious games can be used to support parents and children in developing these life skills. The purpose of this study is to evaluate the effect of a serious game on the performance of daily routines by autistic and ADHD children. **Method.** A total of 201 families (parents and children) participated in the study. The study used a combined 3 (intervention) X 3 (diagnosis) X 3 (time) research design with repeated measures. Participants were randomly assigned to three intervention groups (serious game, parental support alone and a combination of serious game and parental support) based on their diagnosis (ASD, ADHD, neurotypical). Latent growth modeling and repeated ANOVAS were performed to analyze routine scores collected at three moments (baseline, midpoint, persistence) over an 8-week period. **Results.** Results show a moderating effect of diagnosis on child routine trajectory. For ADHD participants, we observed a very important significant clinical effect for two interventions (parental support and combination of serious game and parental support) where for ASD children this effect is observed for only one treatment (combination of serious game and parental support). For neurotypical children, results indicate a very important and significant clinical effect when they use the serious game alone. **Conclusions.** Results show that the serious game can improve children's routines. However, for some neurodevelopmental profiles (ASD or ADHD) the addition of parental support produces greater clinical improvements.

Keywords: routines, serious game, attention-deficit / hyperactivity disorder, autism.

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Abstract

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According to Fiese (2007), routines play a central role in child development. In addition, other researchers have reported that they promoted harmonious family dynamics (Evans & Rodger, 2008; Segal, 2004). A routine is defined as a sequence of clear and well-established activities and rules related to everyday situations (e.g., getting up, getting ready for school, eating, doing homework, or going to bed; Centre de recherche pour l'inclusion des personnes en situation de handicap [CRISPESH], 2018; Massé et al., 2011). Barkley (2020) indicates that routines take different forms depending on the time of day (morning, home from school, evening), the time of year (school or vacation), or the child's age. They also represent markers that make the child aware of parental expectations and help the child benefit from a predictable, stable, and safe environment (Fiese, 2006; 2007). Massé et al. (2011) determined that routines also constitute a common ground between the child and parents about family rules. Studies showed that this environment can, among other things, prevent the occurrence of some behavioral problems (Bagatell, 2016), promote positive child participation (Coussens et al., 2020), and solve common discipline problems related to getting ready for school, bedtime or doing homework (Bridley & Jordan, 2012; Delemere & Dounavi, 2018). Lastly, several studies demonstrated that routines contribute to the development of a child's independence, autonomy, sense of responsibility, and self-esteem (George & Soloman, 2008; Martin et al., 2012).

In families of children with neurodevelopmental disorders such as attention deficit / hyperactivity disorder (ADHD) or autism spectrum disorder (ASD), routines are strongly associated with lower levels of externalizing and internalizing behavior (McRae et al., 2019; Stoppelbein et al., 2016) and a higher quality of life (Bowling et al., 2019; Schlebusch et al. 2016).

A number of researchers reported that autistic and ADHD children find learning, adopting, and performing new routines challenging mainly because they face difficulties with executive functioning (Barkley, 2015a, 2015b; Sinzig et al., 2014). Although manifestations might vary depending on the individual and diagnosis, these children often struggle with activation, behavioral or emotional self-regulation, inhibition, cognitive flexibility, planning, organization, attention, working memory, or time management (Barkley, 2015a; Sinzig et al., 2014). For example, an emotional self-regulation issue might result in low motivation and consequently hinder engagement and tolerance to delayed gratification. In contrast, behavioral self-regulation difficulties could impair a child's performance. Furthermore, poor planning, organizing skills working memory and time management might interfere with a child's ability to consistently prepare and coordinate routines. For autistic children, behaviors associated with aggression (Hodgetts et al., 2013) and sensory processing (self-stimulation, sensory avoidance, sensory seeking) represent the challenges faced with routine completion (Bagby et al., 2012; Scaaf et al., 2011). In addition, their propensity to desire sameness could interfere with parents' requests and expectations concerning routines (McRae et al., 2018).

With respect to parents of autistic and ADHD children, many studies highlighted the challenges they have encountered in establishing and maintaining healthy, productive routines (Hodgetts et al., 2013; Schaaf et al., 2011). Research showed that mornings, mealtimes, homework, bedtime, and household chores were particularly difficult for them (Firmin & Phillips, 2009; Taylor et al., 2008) requiring substantial parental guidance, consistency and frequent reinforcement, which can become burdensome (see Bagby et al., 2012; Corcoran et al., 2017). Sallee's (2015) study reports that parents feel overwhelmed, exhausted, and constantly stressed with routines. Johnston and Mash (2001) also demonstrated that parental stress affects the relationship parents built with their child. This situation could lead to a decrease in positive interactions or an increase in negative remarks, which, in turn, influence children's self-esteem. Larson (2006), stated that mothers of autistic children found it difficult to manage and maintain routines in their families. In the case of ADHD, 10% to 20% of mothers and nearly 50% of fathers report having ADHD symptoms themselves (Kessler et al., 2006). Such parental difficulties might represent another risk factor interfering with the management of routines, as expressed by Dawson et al. (2016), and Gray et al. (2020).

Several studies explored the effects of different interventions on routine completion. Some authors suggested that an ABC (antecedents, behaviors, consequences) grid is useful in helping parents understand the causes of certain problem behaviors and their impacts on routines for autistic children from 3 to 9 years old (Lucyshyn et al., 2018; Sears et al., 2013) or for ADHD children from 3 to 17 years old (Dekkers et al., 2022). Coaching and guiding children are also considered important factors associated with the intervention successfully impacting daily routines. Pictograms might help the autistic or ADHD child remember the sequence of steps in the routine (Goldman et al., 2018) and could be related to time reminders (Barkley, 2020; Massé et al., 2011). Banda et al. (2009) stated that visual interventions increase engagement and task completion rates of elementary autistic children. Additionally, some authors recommended supporting the child's problem-solving ability for ADHD children (Barkley, 2020; Massé et al., 2011). Consistency of the parents' expectations is also proved to be essential (Barkley, 2020).

While positive reinforcement has been successful with ADHD and autistic people across the lifespan, several researchers specifically found that positive reinforcement encourages the expression and perpetuation of expected behaviors and highlights the child's efforts and improvements ADHD children from 3 to 17 years old (Dekkers et al., 2022; Sawyer et al., 2015) or autistic children from 3 to 9 years old (Sears et al., 2013). Concerning reinforcement, Slattery et al. (2016) mentioned that positive child involvement is beneficial for ADHD boys from 9 to 12 years old. Kazdin (2013) also stated that effective reinforcement should meet certain conditions (alternating different strategies, avoiding negative criticism, using visual techniques such as a motivational chart or stickers). In sum, the process of planning and supervising daily routines can be challenging for families and especially those involving children with neurodevelopmental disorders. To ensure the effectiveness of interventions, constancy in child reinforcement (Barkley, 2020) and parental support could provide valuable leverage (Lucyshyn et al., 2018; Sears et al., 2013).

Recent studies also suggested that computer-based interventions, such as serious games, might be useful in supporting routine completion for autistic and ADHD children. A serious game is a digital solution that combines an educational and informative intention in a learning environment using game components (Perron, 2012). Serious games can take many forms, from console or computer to mobile games (Zheng et al., 2021).

In a literature review, Kokol et al. (2020) identified interventions using serious games for children and young adults (ages 2-24) with developmental disabilities. Of the 145 studies, 45 were conducted with children with autism and 24 with ADHD children. These authors conclude that these intervention procedures have the potential to regulate stress and emotions as well as reducing anxiety of children with neurodevelopmental disorders.

In the area of ADHD, preliminary results from early studies support those conclusions. For example, the literature review by Cibrian et al (2022) notes that serious games engage children in the learning process and add a new range of intervention tools to support the development of academic and life skills. By providing interactive experiences, serious game intervention can support behavioral motivation and improve engagement among children. In their review, Zheng et al (2021) noted that the use of serious games as a treatment procedure with these children improved daily life skills, increased enthusiasm and promoted positive social interactions. More specifically, in relation to the executive functions, it has been observed that some serious games can have a positive effect on attention, working memory and emotional regulation. Some authors have also questioned possible gender differences. In this regard, only one study (Bul, 2017) observed greater improvements for the girls.

Of the 19 articles analyzed by Sandgreen et al, (2021) in their meta-analysis on the use of digital intervention with individuals with autism, 14 specifically targeted children. Of these, only one used a serious game with 7-year-olds to support emotion recognition (Fridenson-Hayo et al., 2017). The study, conducted over 8 weeks with an intervention group (n=34) and a control group (n=40), revealed a small clinical effect (Cohen's *d* 0.40). Vallefuoco et al (2022) use the serious game specifically for the development of daily living skills related to shopping procedures (learning steps, attention toward tasks and problem solving) with adolescents (mean of 11.9 years). The study revealed a significant improvement in adaptive skills as measured by the Vineland (VABS-II). Finally, in their review of the literature, Kokol et al. (2020) mentioned that serious games can improve recognizing emotions, concentration, motivate attention and enhance social life. These results show that this area of research is unfolding and that the use of this type of intervention is more documented in the field of ADHD. According to Whyte et al, (2015), serious game intervention could be complementary and cost-effective intervention methods that can be used in a variety of settings.

Essentially, the studies emphasize that ADHD and ASD children have difficulty carrying out their daily routines. The authors therefore insist on the importance of interventions supporting both children and parents. The present study used computer-based intervention to improve routines of autistic and ADHD children. Specifically, the main objective was to compare the effects of a serious game and parent coaching on the execution of daily routines across diagnosis through a repeated measures research design.

Method

Participants

The sample size was set by with G*Power 3.1 (Faul et al., 2009) and the following parameters were used: (1) effect size of 0.25 (proposed by Cohen, 1988); (2) Type I error of 5%; (3) test power: Type II error of 80%; (4) 12 group comparisons; (5) three repeated measures; and (6) a nonsphericity epsilon (ε) correction criterion of 1. Calculations established a sample size of 192 participants leading us to a critical F of 1.57 (numerator degree of freedom of 22 and denominator degree of freedom of 360) and an estimated statistical power of 0.80. Ethical concerns related to the assignment of children with neurodevelopmental disorders in control conditions (without any interventions) arose in the context of COVID-19 pandemic. Consequently, the research team decided to eliminate this condition and limit the number of groups to nine, thereby increasing the statistical power of the analyses (0.82).

Parents and children were recruited through a database created by the Neuro Solutions Group. To be included in this database, parents provided information about the family status, the number of children in the family and the technology they are currently using. For each child, they also provided details about their neurodevelopmental profile (neurotypical, ADHD, ASD, Intellectual disability) and specified if visual, motor or hearing impairments were present. They also authorized the Neuro Solution Group to share sociodemographic information with the research team. The list sent to researchers included this information as well as the contact details for 383 families. Among them, 320 met the following inclusion criteria: (1) family with a child (neurotypical, ADHD or ASD) between 6 and 12 years of age; (2) residence in the province of Quebec (Canada); (3) fluent in French; and (4) a Wi-Fi network. Children diagnosed with an intellectual disability and those with motor or visual impairment, as reported in the database, were excluded from the sample. All participants were contacted by email. The message included a brief presentation of the research project and an internet link giving access to additional information and a consent form. Electronic consent was preferred because the researchers wanted to have a maximum of participants in a huge territory. A total of 201 children participated in the study. This deliberate oversampling was intended to prevent a decrease in statistical power due to possible attrition over time. Table 1 presents a description of children's gender and clinical profile.

INSERT TABLE 1 HERE

In regard to the parents' profile, most mothers had either a college (29.8%) or a graduate degree (52.3%), whereas a little more than two-thirds (68.9%) of the fathers had an undergraduate degree. The majority (71.5%) of the families had an annual income of $75,000 or more. It should also be noted that, on average, the families mentioned having experienced 2.09 stressful events since the beginning of the school year during which the study was conducted. These events included the COVID-19 pandemic, access to new medical or psychosocial services for their child, and adjustment of the child's medication. Lastly, parents provided information about their past and current interventions on daily routines. Some of the most common approaches used were parental supervision, direct help or assistance, medication, and cutting back on their requirements of the child.

Procedures

The study used a combined 3 (diagnosis) X 3 (intervention) X 3 (time) research design with repeated measures of the time variable. Initially, the 201 participants were classified by diagnosis and then randomly assigned to one of the three intervention groups. Table 2 shows the distribution of participants.

INSERT TABLE 2 HERE

In Group 1 both children and parents were targeted by the intervention. Children had access to a beta version of a serious game (Kairos) providing support and rewards for the accomplishment of daily routines (e.g., breakfast, making the bed, doing homework, brushing teeth). At specific moments (scheduled by the parents in the private section), the avatar sent a reminder to the children and invited them to perform a specific routine. The avatar also helped them by presenting its steps. Once completed, the routine is immediately reinforced by appraisals from the avatar. The Kairos application then prompted the parents to confirm the routine completion. Afterward, children were awarded points and powers that could later be used by the children to customize or help the avatar in the serious game. Avatar upgrades provide unique skills that were necessary to progress in the video game. Kairos integrated the core elements of a serious game and designing guidelines for ADHD and autistic children (Powell et al., 2019; Whyte et al., 2015).

In Group 1, parents had access to parental support integrated in a private section of Kairos. This section was created by researchers in the field of psychoeducation and based on an intervention program developed by Massé et al. (2011). The parental support was presented in the form of guidelines regarding the implementation of daily routines. Designed as a simple and accessible information database, the guidelines addressed routines with different angles. It first gave tips about four key routines (morning routine, meals, homework, and sleep). Secondly, it presented suggestions on planning and managing routines to promote autonomy (e.g., strategies to facilitate performing routines, qualities of good directive, positive reinforcement, children's physical development, ABC grid). Lastly, a reference section provided a list of hyperlinks for additional information.

In Group 2, the intervention was exclusively focused on children. Children in this group used the serious game (support and rewards) but the parents didn't have access to parental support. In Group 3, the electronic tablet and the serious game were unavailable to children. Parents in this group only had access to the parental support presented on the electronic tablet. This information was identical to the one provided to parents on Group 1. Participants were free to consult or use this information. Throughout the study, parents were able to communicate with the research team for questions related to the study or with the Neuro Solutions Group for technical questions. This study was conducted over an 8-week period (March to May 2021) three moments were identified for the repeated measures.

Baseline (Time 0). At baseline, all parents were invited to complete the electronic version of the Routine Achievement Assessment Tool and the Sociodemographic Questionnaire. Once the questionnaires had been completed, an electronic tablet (Samsung Galaxy Tab A – approximately C$175) has been sent to the families. Parents of the 3 intervention groups also had to identify one challenging routine that their child had to perform between Time 0 and Time 1 (e.g., getting ready for school, doing homework, going to bed). This routine had to remain the same for the first 4-week period. In Groups 1 and 2, parents had to set up all the components associated with the chosen routine in the Kairos app preinstalled on the electronic tablet. A straightforward, intuitive interface located in a private secured section guided parents in setting up all the components (identification of routine, task sequence, time scheduling, and reinforcement). The beta version used in this study was not context aware and parents had to regularly validate routines executed by their child in their private section. Parents had to complete this setup in order to activate Kairos' reminders and reward system. Lastly, parents and children from Groups 1 and 2 were invited to create together a game avatar.

Halfway measure (Time 1). After the first 4-week period, an email was sent to all parents to remind them to complete the Routine Achievement Assessment Tool for a second time. At this moment, parents from Groups 1, 2 and 3 were allowed to change routines if they judged that their child had acquired it. This choice was based on parents' perceptions and no criteria or routine mastery standards were provided to guide them in this decision-making process.

Persistence measure (Time 2). The last part of this study consisted in a persistence measure 4 weeks after the halfway measure (or 8 weeks after Time 0). For the last time, all parents completed the Routine Achievement Assessment Tool. After this period, all the participants (Groups 1, 2, and 3) who completed all the assessment tools were given unlimited access to the retail version of Kairos.

Adjustments due to the COVID-19 Outbreak. COVID-19 had an impact on the experimental protocol planned by the research team. The study couldn't be postponed for a number of reasons. First, electronic tablets were sent out weeks before the COVID-19 outbreak started in Quebec. Second, the baseline data had already been collected when the government decided to close temporarily schools as COVID-19 spread throughout the province. The research team was concerned about the attrition and the possible loss of thousands of dollars of material already in the hands of participants. Accordingly, the team decided to make some methodological adjustments. Consequently, we so informed families and encouraged them to follow the protocol. The study was put off for two weeks to let them adapt to this new situation. It is important to point out that the participants had the right to drop out of the project without any consequences. They were also allowed to keep their electronic tablets.

Measures

Sociodemographic Questionnaire. This parent-report online questionnaire was used to complete the sociodemographic data gathered in the Neuro Solution Group database. Parents provided information about stressful events since the beginning of the school year, income, and their level of education.

Routine Achievement Assessment Tool. An adapted version of the Before School Functioning Questionnaire (BSFQ; Wilens et al., 2010) was used to evaluate the effects of interventions on the children's routines. The first adaptations were a French-language translation involving a committee approach and a forward-only translation with testing (Maneesriwongul & Dixon, 2004). A second adaptation was intended to adjust the instrument to the study objectives, the COVID-19 context, and Kairos features. Given that our study focused on routines throughout the day, the researchers significantly adapted the original instrument. First, they removed items targeting specific tasks (getting dressed, personal hygiene, meals, misplacing and losing items). Second, they rephrased some items to make them easily observable by parents. Third, they deleted items not specifically related to routines (be calm and quiet, be hyperactive, awaiting turn, interrupt and blurt out). The researchers also added new items associated with cognitive functioning and made sure that each executive function was evaluated (attention, working memory, self-regulation, managing frustration, organizing, following directions, time management). These adaptations were based on the scientific literature and the researchers' expertise concerning the effects of executive functioning on routine achievement (Massé et al., 2011). Lastly, the original Likert scales were adjusted with the addition of a "does not apply" option.

In the final version, the parents were asked to indicate their level of agreement with 20 statements (the BSFQ also has 20 items) on a 6-point Likert scale (strongly disagree, disagree, somewhat disagree, somewhat agree, agree, strongly agree). An average score was calculated and then divided by the number of items answered. A low score indicates problems with routine achievement. The parents completed the instrument in an average time of 5 minutes. Post-study analysis shows that the instrument has good internal consistency (Cronbach's alpha of .87) (Simonato et al., 2022).

Data analyses

Latent growth modeling (LGM) was used to analyze routine scores collected over the 8-week period. According to Marcoulides (2019), LGM is currently the most popular method of analysis in social and educational studies when repeated measures are gathered. Acknowledged for its reliability and robustness, it allows for analysis of continuous, dichotomous, or categorical values. Part of the structural equation modeling family of statistical analysis, LGM specifically evaluates relationships between variables using variance and covariance matrices. This analysis represents a valuable alternative to repeated ANOVA measures or hierarchical linear modeling, since it simultaneously addresses between-subject and within-subject variability (Bryk & Raudenbush, 1992). LGM also enhances statistical techniques by providing optimal management of missing data (Curran et al., 2010).

At first, descriptive and correlational analyses were performed to verify the distribution of longitudinal variables and explore correlations over the different time periods. No distribution abnormality was observed. Therefore, different models were tested using the maximum likelihood estimation (MLE) method for normal distribution. Moreover, the significant correlations showed relative score stability over time. To compensate for missing data, model estimations were calculated with the full information maximum likelihood (FIML) option. This technique estimates model parameters using the maximum information available from the covariance matrix without excluding subjects with missing data.

A four-step analysis was performed. First, the average longitudinal trajectory of the sample across the three measurement times was estimated with a baseline model precisely calculated with a LGM with two latent factors. The factors were the intercept (initial status) and the slope (direction and rate of change over time). The second step of the analysis (Model 2) evaluated the effects of three covariates (age, gender, and intervention) on the variation of the slope and the intercept of the average trajectory. The moderating effects of children age and clinical profile (ASD, ADHD, or neurotypical) on routine score trajectories were tested in the third phase. Statistics such as the chi-square test (Bollen, 1989), root mean square error of approximation (RMSEA; Brown & Cudeck, 1993; Hu & Bentler, 1999), and comparative fit index (CFI; Bentler, 1990) were used to validate the models. Lastly, repeated ANOVAS measures were performed to improve our understanding of the effects of moderating variables on the variation of routine score trajectories. Cohen's *d* statistic was calculated to weigh the magnitude of the observed differences. Score interpretation was based on Sawilowsky's (2003) criteria.

Results

First, the results presented in Table 3 show that the ADHD participants were largely overrepresented in the sample. At Time 0, however, the number of participants per intervention group was almost equivalent. Descriptive analyses reveal an overall sample attrition of 10% over the 8-week period. The ADHD group had the highest attrition rate (-14%), followed by the ASD (-7%) and neurotypical (-6%) groups. In regard to routine scores, Table 3 shows an overall improvement of child routines regardless of clinical profile or intervention method.

INSERT TABLE 3 HERE

The Pearson correlation coefficients were calculated to explore participant stability between measurement periods. The strong correlations presented in Table 4 suggest that the participants maintained their relative group positions between measurement times. These scores are expected in longitudinal designs (Deković et al., 2004).

INSERT TABLE 4 HERE

Table 5 presents the results from LGM trajectory models over the 8-week period. To simplify the presentation of the results, all models have been combined in a single table. All contrasts are the results of two regression analyses.

INSERT TABLE 5 HERE

The baseline model (Model 1) presents the average trajectory of children who participated in the study without considering the clinical profile or the experimental conditions. On average, the children had a routine score of 3.17 (p = .00) at the intercept (T1). This score increased significantly over the three measurement times with a slope of .07 (p = .04), showing overall improvement in the children's daily routines. The significant variation in intercept and slope indicates heterogeneity in the mean trajectory and justifies the inclusion of covariates to explain the variances.

The second model tested the effects of covariates (age, gender, and intervention group) on the children's routine scores. The results revealed no significant difference between groups at the intercept. Therefore, neither age nor gender was associated with the score at T1. Significant effects on the slope, however, were observed. First, a negative effect of age indicated that the youngest participants experienced the greatest improvement in routines. The group effect also suggested that Group 1 (combination of serious game and parental support) improved marginally more than Group 2 (serious game alone) (p = .07) and significantly more than Group 3 (parental support alone) (p = .03). There were no significant differences between the slopes of Group 2 and Group 3.

Model 3 presents the moderating effect of age on routines according to the intervention group. The nonsignificant results revealed that the observed differences in trajectories across intervention groups were not moderated by age.

Lastly, the interaction effect observed in the last model (Model 4) confirmed a moderating effect of diagnosis on child routine trajectory. Post-hoc analyses were then performed to understand the moderating effect of diagnosis on trajectories. Table 6 presents the results of the ANOVAS.

INSERT TABLE 6 HERE

The Figure 1 presents the effect size calculated by the mean of Cohen's *d* analyses.

INSERT FIGURE 1 HERE

The post-hoc analyses revealed a very large clinical effect (d > 1.2) on the routines of ADHD participants when two interventions modalities were used (combination of serious game and parental support and parental support alone). This effect was mainly between Times 0 and 1 (first 4 weeks). It is important to point out, however, that, for these two interventions, the overall effect after 8 weeks was less than the initial effect observed during the first 4 weeks. It should also be mentioned that using serious game alone had a significant medium clinical effect (d = 0.72) on the ADHD group; 8 weeks were needed to observe this effect.

For autistic children, significant differences between measurement times were observed but only when serious game and parental support were combined. The data also show that a huge significant clinical effect (d = 2.81) occurred after 8 weeks. A very large and significant clinical effect (d = 1.55) also occurred in the first 4 weeks. These results suggest that the routines of autistic children only improve when intervention focused on both children and parents.

For the neurotypical children, the analyses revealed a huge significant clinical effect (d = 2.28) of the serious game on the routine scores. As for the ADHD children, the overall effect after 8 weeks was smaller than that observed in the first 4 weeks (d = 2.09) but remained quite large. For neurotypical children, the use of parental support also improved the routines in the first 4 weeks; the clinical effect was large (d = 1.12) and significant. After 8 weeks, the clinical effect remained significant but decreased slightly (d = 1.08). Lastly, it is important to point out that the inconsistencies between ANOVA and Cohen's *d* results for the neurotypical children in the serious game and parental support condition (Group 1) may be explained by the small group size. However, the p-value is very close to the significance level of 0.05.

Discussion

Several scientific studies evaluated the effects of parental guidance and supervision on the execution of daily routines by children with neurodevelopmental disorders (Dawson-Squibb et al., 2020; Kucharczyk et al., 2019). Recently, serious games have been added to the intervention spectrum, yielding encouraging preliminary results (Kokol et al., 2020). This study is part of this course of action and specifically evaluated the effects of a serious game and parental support on the performance of daily routines by children between the ages of 6 and 12 years with a neurodevelopmental disorder (ASD or ADHD). The serious game (Kairos) used in this study was created by the Neuro Solutions Group in accordance with clinical and scientific recommendations provided by clinicians and researchers (motivating storyline, contextualized learning, targeted skills to accomplish incremental learning goals, rewards, time reminders and feedback; Barkley, 2020; Whyte, 2015). It is also in phase with serious games' designing guidelines for ADHD children (instant positive reward, customizable virtual environments, imitation learning, short-term goals, and the use of an avatar that the child can relate to; Powell et al., 2019) and autistic children (use dynamic stimuli to gather attention, predictability, repeatability, motivating storyline, explicit goal; Carlier et al, 2020; Whyte et al., 2015).

The results from the 8-week experiment show an overall improvement in the daily routines of children regardless of diagnosis or intervention/treatment. LGM, however, shows that diagnosis and treatment influence the trajectory of routine scores over time. Thus, for neurotypical children, the serious game induces a large clinical effect on routines in the first 4 weeks of use. This large effect is also observed in the ADHD children but only when the serious game and the parental support were combined over a longer period (8 weeks).

In sum, these results suggest that, under certain conditions, serious games can be clinically effective in improving some aspects of daily routines (e.g., understanding and following instructions, listening, task organization, forgetting steps, procrastination and time management) and outweigh children's difficulties affecting routine learning and completion (activation, self-regulation, inhibition, planning, organization, attention; Barkley, 2015b; Sinzig et al., 2014). Furthermore, the results indicate that parental support significantly improve the routines of neurotypical and ADHD children. In the case of autistic participants, the effectiveness of parental support increases when it is paired with the serious game. These findings also highlight the benefits of less restrictive parenting practices (Dose et al., 2017). Moreover, they stress the importance of parental support when implanting new intervention modalities. As a matter of fact, parents facing challenges with their parental practices might struggle with adopting different methods, which might have a negative effect on the adoption or sustainability of effective daily routines (Dawson et al., 2016; Gray et al., 2020). Lastly, the fact that the youngest participants achieve the greatest routine improvement might be explained by the conclusions reached by Dunn et al. (2009), who stated that younger children appear to benefit more than older children from intensified parental supervision in routine completion. However, for AHDH children age didn't seem to have a moderating effect on parental interventions (Lee et al., 2012).

Several authors have mentioned that children using technology can be a concern (Alghamdi, 2016; Mustafaoğlu, et al., 2018). To limit the influence of this ethical issue, the research and design teams implemented a number of preventive measures. First, an information module was included in Kairos. Created by clinicians and researchers, this part included tips on screen time management, signs indicating that technology use could become problematic, and useful references. In addition, the design team ensured that mission completion—used as daily reinforcement in the video game—does not exceed 5 minutes. Lastly, the researchers encouraged the designers to include information in the commercialized version on how to slowly and gradually substitute social reinforcement for the tangible reinforcement. This phasing out has been recognized as an important part of behavior modification interventions (Kazdin, 2013).

Limitations and Future Research

The study has some limitations. First, the context of COVID-19 pandemic greatly influenced its conduct. Initially, the study was to be carried out during the school year (March to May 2020); and the first 4 weeks were to be devoted to morning routines (before leaving for school). When the study began, however, the Quebec government announced that schools would be closed indefinitely. Considering the significant financial investment (more than $30,000 worth of materials had already been sent to participating families), the requirements of the funding agencies, the risks of sample attrition, and the ethical issues related to the consent already obtained from parents, the researchers decided that it was better to continue the study, allowing families to choose whether to include the morning or evening routines. Clearly, the exceptional context of school closures affected the implementation of the routines, but it also seemed that the study allowed families to maintain some structure in a context of great uncertainty. Moreover, the low level of attrition in the sample (10%) testifies the participants' desire to maintain a certain number of routines in their daily lives. In sum, the experimental context was not optimal. Several research biases influenced the external validity of the research and thus limit the possibilities of generalization to a post-pandemic context. Nonetheless, the strengths of the design and analyses allow us to believe that the intervention modalities did indeed positively influence children in a health crisis.

As another limitation, the protocol allowed parents to change the routine between halfway and persistence measures. Furthermore, parents were not supported in this decision-making process and mastery criteria were not provided to participants. This unsupervised change made by parents probably induced variability and influenced the score on the Routine Achievement Assessment Tool. Lastly, the study only measured the effect of the interventions on global routine execution. The scientific literature stated, however, that a systemic approach was more appropriate when studying routines (Coussens et al., 2020; Fiese, 2007).

Future studies should include evaluation of other aspects of routines related to children (e.g., self-esteem, behavioral problems, and positive participation), parents (e.g., stress, parental self-efficacy, self-esteem, and depression), and family environment (e.g., harmony, predictability, sibling relationships, and stability and security of the family setting). It might also be interesting to assess collateral effects outside the family setting such as school. Future studies should address the moderating effect of age. Lastly, mixed protocols including qualitative measures might be useful in gaining a better understanding of children's and parents' perceptions about the use of technologies in their household.

Conflict of interest. The research grants were awarded to the UQTR Research Team and the NeuroSolution Group to conduct collaborative research. The research team does not receive any benefits from the marketing of the product created by the NeuroSolution Group.

Ethical approval. The study was approved by the Université du Québec à Trois-Rivières research ethics committee and was conducted in accordance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans – TCPS 2* (2018). The certificate (CER-19-261.07.03) was obtained on November 7, 2019.

Informed consent. Informed consent from each parent who participated in the study was obtained electronically.

Author contributions

DLD: designed and executed the study, collaborated to data analyses, wrote and translate the final manuscript. LM: collaborated with the design of the study, the development of the virtual coach and the Routine Achievement Assessment Tool and collaborated in the writing of the final manuscript. IS: collaborated in the execution of the study and data analyses. YL: collaborated with the design of the study, translation and the writing of the final manuscript. VGT: was responsible of the development of the virtual coach. AL: analyzed the data and wrote part of the results. All authors approved the final manuscript.

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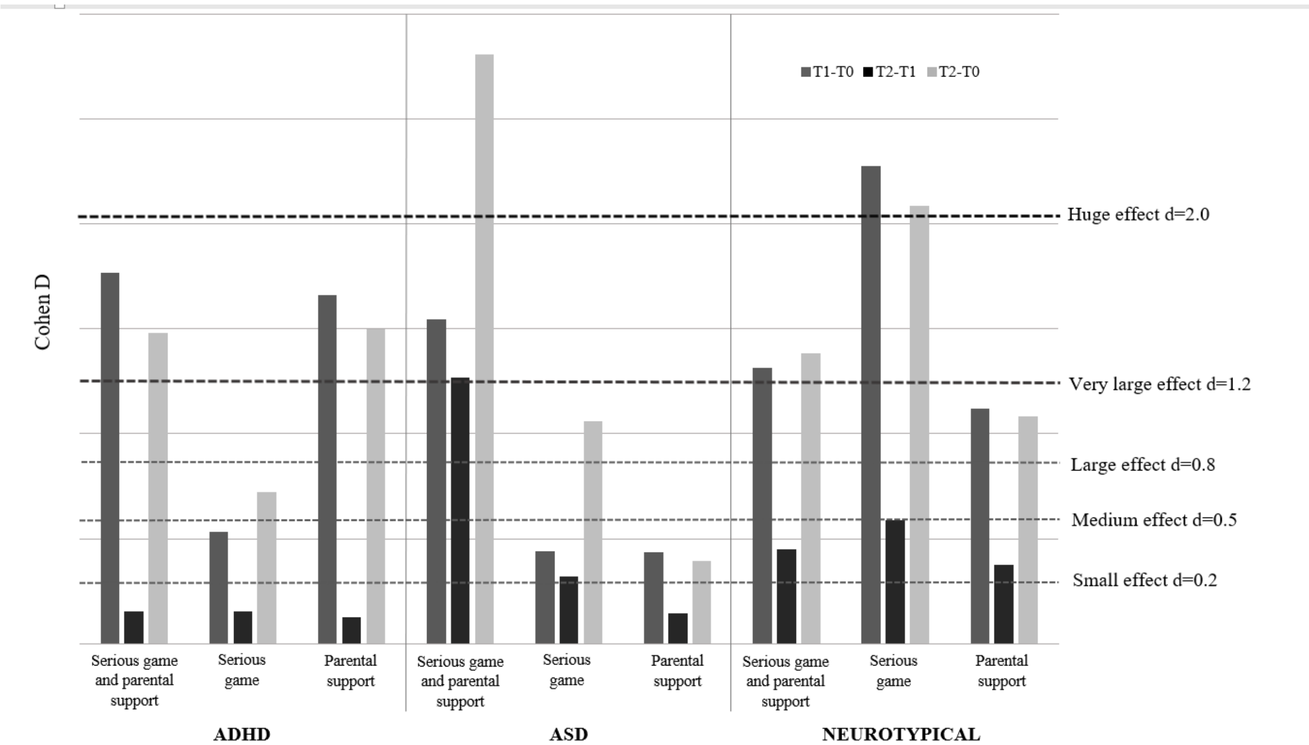
Figures

Figure 1

Results of Cohen d analyses for the diagnosis and intervention groups



Tables

Table 1

Sample demographics by gender and diagnosis (*N* = 201)

	Neurotypical	ADHD	ASD	Total
Girl	25	28	9	62
Boy	28	76	35	139
Total	53	104	44	201

Table 2

Distribution of participants by intervention group and diagnosis (*N* = 201)

	Neurotypical	ADHD	ASD	Total
Serious game and parental support (Group 1)	16	36	14	66
Serious game (Group 2)	17	35	15	67
Parental support (Group 3)	20	33	15	68
Total	53	104	44	201

Table 3

Mean scores and standard deviations of routine scores by intervention and clinical profile over the 8-week period ($N = 201$)

Measure	Time 0 (Beginning)			Time 1 (4 weeks)			Time 2 (8 weeks)		
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Serious game and parental support (Group 1)									
Neurotypical	16	3.06	0.73	16	3.65	1.08	15	3.48	1.00
ADHD	36	2.61	0.50	27	3.38	0.93	25	3.13	0.90
ASD	14	2.67	0.50	15	3.36	1.03	14	3.86	1.08
Total (Group 1)	66	2.73	0.59	58	3.44	0.99	54	3.41	1.00
Serious game (Group 2)									
Neurotypical	17	2.95	0.68	17	3.56	0.78	16	4.01	0.96
ADHD	35	2.79	0.76	32	3.05	0.98	31	3.17	0.83
ASD	15	2.84	0.84	14	2.97	0.70	12	3.24	0.64
Total (Group 2)	67	2.84	0.75	63	3.17	0.89	59	3.41	0.90
Parental support (Group 3)									
Neurotypical	20	2.89	0.72	17	3.03	0.86	19	3.21	0.89
ADHD	33	2.57	0.60	31	3.26	0.81	33	3.11	0.74
ASD	15	3.01	0.89	14	3.16	0.64	15	3.18	0.60
Total (Group 3)	68	2.76	0.72	62	3.17	0.78	67	3.15	0.75
All conditions									
Neurotypical	53	2.96	0.70	50	3.40	0.94	50	3.54	0.99
ADHD	104	2.66	0.63	90	3.22	0.91	89	3.14	0.81
ASD	44	2.84	0.76	43	3.16	0.81	41	3.43	0.85
Total	201	2.78	0.69	183	3.26	0.90	180	3.32	0.88

Table 4

Person correlation coefficients for the three time periods (*N* = 201)

	Time 0	Time 1	Time 2
Time 0 (Beginning)	---	.40***	.40***
Time 1 (4 weeks)	.40***	---	.54***
Time 2 (8 weeks)	.40***	.54***	---

* $p \leq .05$. ** $p \leq .01$. *** $p \leq .001$.

Table 5

Results of the analyses of the LGM trajectory models over the 8-week period (*N* = 201)

	Model 1	Model 2	Model 3	Model 4
Intercept (value)	3.17 (.05)***	3.03 (.26)***	3.22 (.13)***	2.74 (.28)***
Slope (value)	.07 (.03)*	.42 (.17)*	.13 (.08)	.50 (.18)**
Intercept (variance)	.28 (.08)***	.28 (.08)***	.28 (.08)***	.27 (.08)***
Slope (variance)	.11 (.04)*	.10 (.04)*	.09 (.04)*	.09 (.04)*
Covariable effects on the intercept				
Age		.03 (.03)	.04 (.05)	.05 (.03)
Gender		-.09 (.10)	-.08 (.10)	-.03 (.10)
Diagnosis				-.13 (.05)**
Gr 2 vs. Gr 1		.04 (.12)	.02 (.06)	.02 (.06)
Gr 3 vs. Gr 1		-.01 (.12)	-.01 (.06)	-.02 (.06)
Gr 1 vs. Gr 2		-.04 (.12)	-.02 (.05)	-.02 (.05)
Gr 3 vs. Gr 2		-.05 (.11)	-.03 (.05)	-.04 (.05)
Gr 2 vs. Gr 1 X age			.04 (.06)	
Gr 3 vs. Gr 1 X age			.04 (.06)	
Gr 1 vs. Gr 2 X age			-.04 (.06)	
Gr 3 vs. Gr 2 X age			.00 (.05)	
Gr 2 vs. Gr 1 X diagnosis				.05 (.06)
Gr 3 vs. Gr 1 X diagnosis				.07 (.06)
Gr 1 vs. Gr 2 X diagnosis				-.04 (.05)
Gr 3 vs. Gr 2 X diagnosis				.02 (.05)
Covariable effects on the slope				
Age		-.04 (.02)*	-.06 (.03)*	-.04 (.02)*
Gender		-.08 (.07)	-.09 (.07)	-.08 (.07)
Diagnosis				.02 (.03)
Gr 2 vs. Gr 1		-.15 (.08)	-.08 (.04)	-.08 (.04)
Gr 3 vs. Gr 1		-.19 (.08)*	-.09 (.04)*	-.09 (.04)*
Gr 1 vs. Gr 2		.15 (.08)	.07 (.04)	.07 (.04)
Gr 3 vs. Gr 2		-.04 (.07)	-.01 (.03)	-.01 (.03)
Gr 2 vs. Gr 1 X age			-.06 (.04)	
Gr 3 vs. Gr 1 X age			-.00 (.04)	
Gr 1 vs. Gr 2 X age			.05 (.04)	
Gr 3 vs. Gr 2 X age			.05 (.03)	
Gr 2 vs. Gr 1 X diagnosis				-.13 (.04)***
Gr 3 vs. Gr 1 X diagnosis				-.07 (.04)

Gr 1 vs. Gr 2 X diagnosis	.12 (.04)***
Gr 3 vs. Gr 2 X diagnosis	.06 (.03)*

Note. All model fits were determined with three fit indices according to Hu & Bentler (1999) criteria, i.e., the chi-square test, the root mean square error of approximation (RMSEA), and the comparative fit index (CFI).

* $p \leq 0.05$. ** $p \leq 0.01$. *** $p \leq 0.001$.

Table 6

Results of the repeated ANOVAS for moderating variables on routine score trajectories

Measure		T1-T0			T2-T1			T2-T0		
		n	Diff	p-value	n	Diff	p-value	n	Diff	p-value
Serious game and parental support (Group 1)	Typical	12	0.443	0.052	11	-0.141	0.495	11	0.371	0.053
	ADHD	21	0.760	**0.001*** **	17	-0.048	0.761	19	0.513	**0.006** **
	ASD	10	0.786	**0.045***	10	0.746	0.090	9	1.591	**0.004** **
	Total	43	0.678	**0.000*** **	38	0.134	0.366	39	0.722	**0.000*** **
Serious game (Group 2)	Typical	20	0.701	**0.000*** **	20	0.248	0.215	20	0.949	**0.000*** **
	ADHD	38	0.274	0.114	37	0.062	0.649	37	0.347	0.037*
	ASD	17	0.184	0.394	16	0.119	0.546	15	0.358	0.067
	Total	75	0.368	**0.001***	73	0.126	0.194	72	0.516	**0.000*** **
Parental support (Group 3)	Typical	17	0.206	**0.039***	17	0.092	0.463	19	0.324	0.034*
	ADHD	29	0.655	**0.000*** **	30	-0.064	0.741	31	0.558	**0.000*** **
	ASD	14	0.230	0.449	14	**-0.045***	0.795	15	0.172	0.475
	Total	60	0.428	**0.000*** **	61	-0.017	0.878	65	0.400	**0.000*** **

* $p \leq 0.05$. ** $p \leq 0.01$. *** $p \leq 0.001$.

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