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A novel approach to improve stress regulation among traumatized youth in residential care: Feasibility study testing three game-based meditation interventions

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[Correction added on 4 October 2019, after first online publication: The affiliation of the 1st, 2nd and 5th author has been corrected.]

Abstract

Aim: Many youth in residential care suffer from post-traumatic symptoms that have adverse effects on a range of psychological, behavioural and physiological outcomes. Although current evidence-based treatment options are effective, they have their limitations. Meditation interventions are an alternative to traditional trauma-focused treatment. This pilot study aimed to evaluate three game-based meditation interventions in a sample of traumatized youth in residential care.

Methods: Fifteen participants were randomly divided over three conditions (*Muse*, *DayDream* and *Wild Divine*) that all consisted of twelve 15-minute game-play sessions. Physiological measurements (heart rate variability) were conducted at baseline, post-treatment and during each intervention session. Post-traumatic symptoms, stress, depression, anxiety and aggression were assessed at baseline, post-treatment and 1-month follow-up.

Results: Physiological stress regulation was improved during the meditation sessions of all three interventions. User evaluations were in particular high for *Muse* with a rating of 8.42 out of 10 for game evaluation. Overall, outcomes on psychopathology demonstrated the most robust effect on stress. *Muse* performed best, with all participants showing reliable improvements (reliable change indexes [RCIs]) in post-traumatic symptoms, stress and anxiety. Participants who played *Daydream* or *Wild Divine* showed inconsistent progression: some participants improved, whereas others remained stable or even deteriorated based on their RCIs.

Conclusions: Preliminary findings show promising outcomes on physiology, psychopathology and user evaluations. All indicate the potential of this innovative form of stress regulation intervention, and the potential of *Muse* in particular, although findings should be considered preliminary due to our small sample size. Further studies are warranted to assess intervention effectiveness effects of *Muse* or other game-based meditation interventions for traumatized youth.

KEYWORDS

adolescents, game-based intervention, meditation, post-traumatic stress, trauma

1 | INTRODUCTION

Youth in residential care have often been exposed to prolonged trauma, such as exposure to domestic violence, neglect and emotional, physical or sexual abuse. Specifically, over 90% of these youth have had traumatic experiences at a young age, of which the majority reports multiple events (Collin-Vézina, Coleman, Milne, Sell, & Daigneault, 2011). Post-traumatic symptoms of youth who suffer from chronic childhood trauma and do not receive appropriate treatment are unlikely to decrease over time (Hiller et al., 2016), which makes effective intervention critical. Exposure to trauma increases the risk of psychological and behavioural problems (eg, anxiety, depression and anger; Collin-Vézina et al., 2011), extreme violence (Welfare & Hollin, 2012), repeated (sexual) victimization (Arata, 2002), health-risking sexual behaviour, delinquency (Smith, Leve, & Chamberlain, 2006), substance abuse (Bowen, De Boer, & Bergman, 2017) and psychiatric disorders at a later age (Carr, Martins, Stringel, Lemgruber, & Juruena, 2013).

Traumatic experiences in early childhood not only have a devastating effect on youths psychological development but also on their physical health (Afari et al., 2014) and physiological stress systems (Beauchaine & Thayer, 2015; Otten, Mun, Shaw, Wilson, & Dishion, 2018). Stress activates the sympathetic nervous system (SNS), resulting in arousal (ie, the fight-or-flight response; Porges, 2007, 2011). The parasympathetic nervous system (PNS), however, is often referred to as the "brake" on sympathetic activity that reduces physiological arousal and promotes recovery after a stressor. Prolonged activation of the SNS results in dysregulation of the stress systems and subsequent stress regulation problems (Bremner & Vermetten, 2001; Corrigan, Fisher, & Nutt, 2011; De Bellis, 2001). A key parameter of the PNS is cardiac vagal control, respiratory sinus arrhythmia (RSA; Porges, 2007, 2011). Higher RSA levels (ie, more variability) are associated with improved abilities to regulate stress and emotional arousal (Graziano & Derefinko, 2013), whereas lower RSA levels are a clinical marker of stress sensitivity and predict post-traumatic stress and psychopathology after traumatic events (McLaughlin, Rith-Najarian, Dirks, & Sherdian, 2015; Mikolajewski & Scheeringa, 2018; Skowron et al., 2011). Post-traumatic stress has been associated with abnormal neurobiological stress responses that are hypothesized to underlie behavioural, cognitive and emotional problems (Bremner & Vermetten, 2001; De Bellis, 2001). Fortunately, these abnormalities can be normalized with treatment (Boyd, Lanius, & McKinnon, 2018).

Although evidence-based treatments such as trauma-focused cognitive behavioural therapy (TF-CBT) and eye movement desensitization and reprocessing (EMDR) have been found effective (Leenarts, Diehle, Dorelijers, Jansma, & Lindauer, 2013), there is considerable debate about whether trauma-focused treatment should start immediately after admission or whether the initial focus should be stabilization (Lindauer, 2015). TF-CBT and EMDR use exposure techniques that can evoke stress and be overwhelming for youth. When youth are unstable and lack the ability to regulate their emotions, arousal and anxiety may exacerbate post-traumatic symptoms and trigger self-destructive behaviour. Even when youth do exhibit the necessary skills in order for trauma therapy to succeed in promoting change, living in a residential institution provides a chaotic living environment that impedes therapeutic progress (Cohen, Mannarino, Kliethermes, & Murray, 2012). Also, youth are often difficult to engage in trauma treatment, because they are still in denial or are not motivated to talk about their traumatic memories (Struik, Ensink, & Lindauer, 2017).

Given the difficulties often faced in traditional trauma treatment, other forms of intervention have gained popularity. A novel approach is meditation-based interventions that can reduce post-traumatic symptoms without direct targeting (Boyd et al., 2018). Instead, the focus is on improving physiological stress regulation. Not only is there no need for youth to talk about their traumatic experiences but also there are no intervention elements that specifically remind them to those events. Relaxation techniques (eg, deep-breathing practises) increase a sense of control over the body and reduce psychological and physiological stress (Pascoe, Thompson, Jenkins, & Ski, 2017).

The present pilot study tested three *game-based* meditation interventions on their potential to improve youths' stress regulation. Game-based interventions are novel strategy to engage youth into treatment and hold advantages compared with traditional forms of therapy. These interventions do not rely on didactic learning but are able to tap into youth's intrinsic motivation (Granic, Lobel, & Engels, 2014). This is promising, as motivation is an important predictor of treatment effectiveness (Harder, Knorth, & Kalverboer, 2012) and youth in residential institutions are usually characterized by a lack of motivation to change their behaviour (Van Binsbergen, 2003). Gamified treatment teaches youth techniques and skills but with *less thinking* and *more doing* (Granic et al., 2014). This way of learning suits them better than memorizing certain principles (Vygotsky, 1978)—as conventional therapy does (Weisz & Kazdin, 2010). The repetitive nature of game play promotes long-term learning (Rosas et al., 2003) and thus may foster generalization of its effects to youth's daily lives.

The aim of the present pilot study was to evaluate the feasibility of three game-based meditation interventions for traumatized youth in residential care. To reach this goal, we assessed the interventions' potential to teach youth how to successfully regulate their physiological stress. We also assessed user satisfaction, and although this was not an effectiveness study, we aimed to show some preliminary effects on post-traumatic symptoms, stress, depression, anxiety and aggression. Our ultimate purpose was to select the intervention that would best fit with our population for a large-scale randomized controlled trial (RCT).

2 | METHODS

2.1 | Participants

Participants were recruited within three open and secured residential youth care institutions for youth with and without intellectual disability (ID). Youth in residential institutions have complex emotional and behavioural problems. They are placed out of home and receive 24-hour care and mental health services. Inclusion criteria are (a) clinical levels of post-traumatic symptoms, measured as a score of 30 or higher on the Children's Revised Impact of Event Scale (CRIES-13; Verlinden

et al., 2014); (b) age between 10 and 18 years; (c) capable to comprehend and speak Dutch and (d) active informed assent to participate in the study from participants themselves and active consent from their legal guardians when participants are under the age of 16. Study participation was discussed with the participant's clinician before the researchers approached eligible participants. Participants who received current or recent (within the last 3 months) trauma treatment were excluded from study participation. There were no restrictions for other types of interventions that participants may receive. We will keep track of additional interventions and use it as a covariate in the analyses if necessary. There were also no restrictions regarding ID or psychiatric disorders as we wanted to obtain a sample that is representative for the population of youth in residential care.

2.2 | Procedure

Ethical review and approval were provided by the CMO Arnhem-Nijmegen under protocol NL58674.091.16. Inclusion criteria consisted a score of 30 or higher on the CRIES-13 (Verlinden et al., 2014). Exclusion criteria were severe psychotic symptoms and current or recent (within the last 3 months) EMDR or CBT treatment specifically targeting post-traumatic symptoms. Eligible participants were invited for an individual meeting with the researcher in which study procedures were explained. Legal guardians were sent an information form. All approached participants and their legal guardians gave active written consent. For a detailed overview, see the flow diagram (Figure 1).

2.3 | Game-based interventions

The three tested interventions all make use of meditation-based relaxation techniques and either neurobeedback or biofeedback, three elements that independently have been found to normalize neurobiological abnormalities of individuals who suffer from post-traumatic stress (Boyd et al., 2018; Reiter, Andersen, & Carlsson, 2016; Schoenberg & Davind, 2014). All interventions consisted of

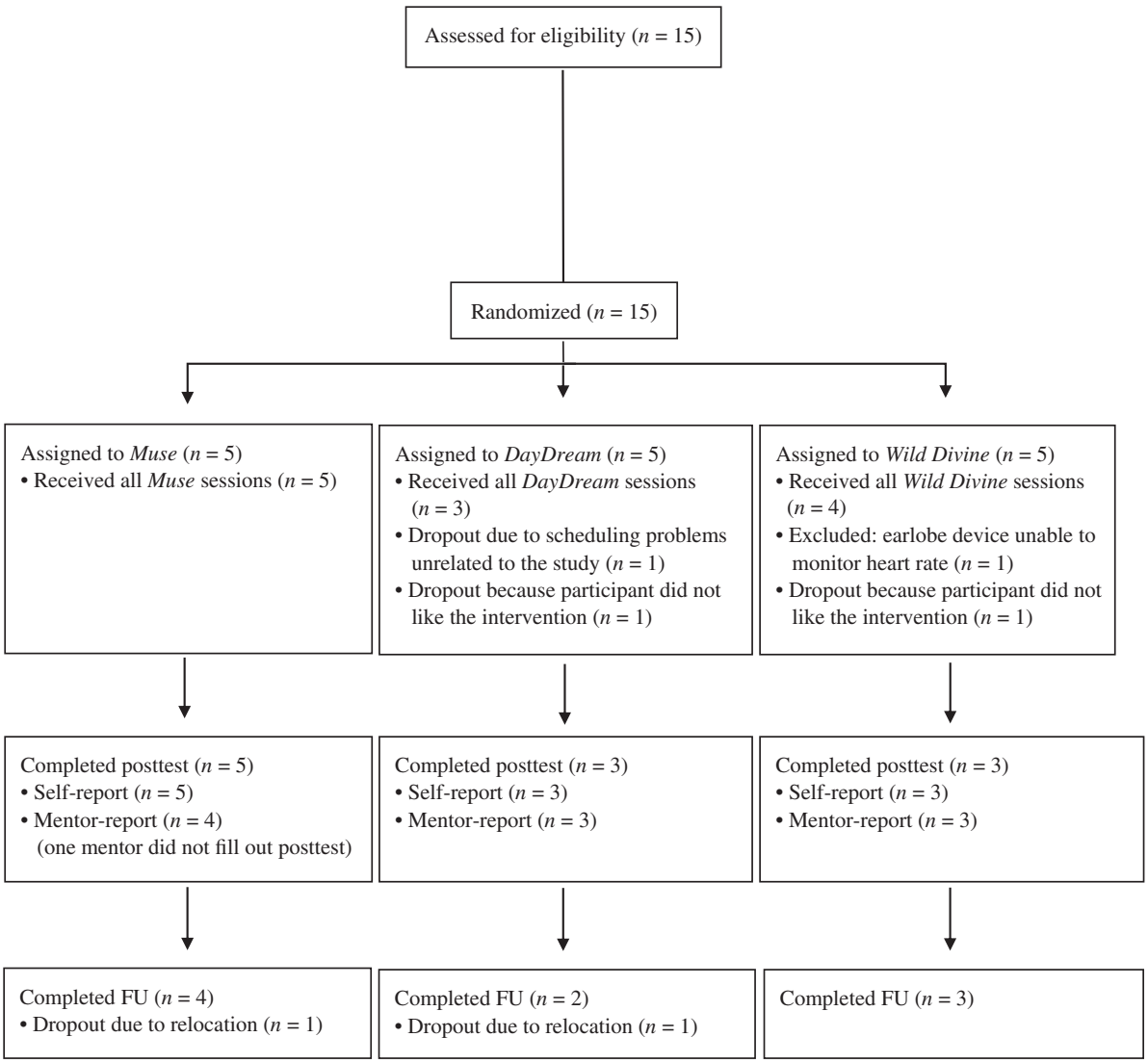


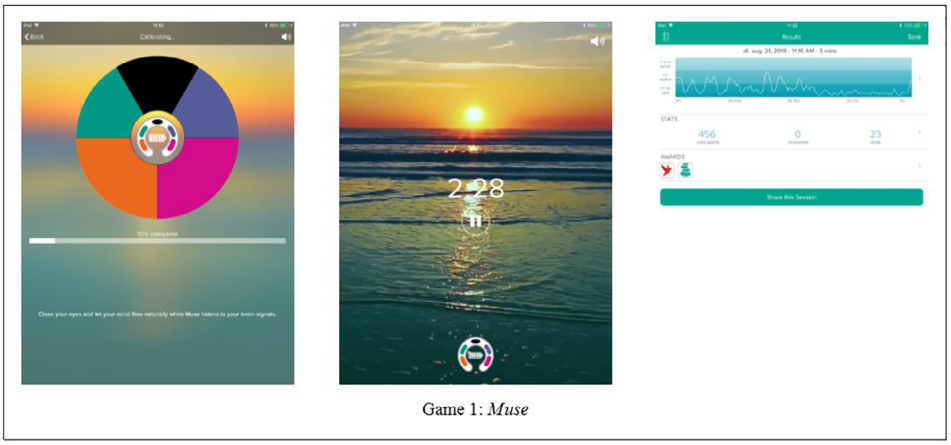
FIGURE 1 Flow diagram

twelve 15-minute sessions during which participants played the selected game. These sessions took place twice a week, for six consecutive weeks, and were led by the first author or a research assistant. Participants were randomly divided over the three intervention conditions in this study (see Figure 2 for game screenshots):

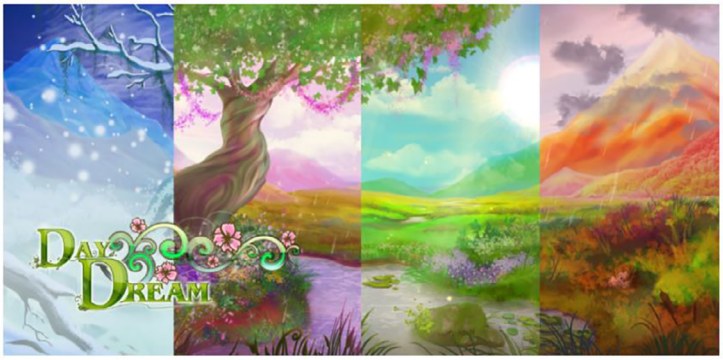
Muse (developed by InteraXon, Toronto, Canada) is a meditation app that is played on an Ipad. The 10 relaxation tutorials resemble elements of CBT (eg, deep-breathing techniques; Weisz & Kazdin, 2010). Each tutorial is followed by a meditation session during which players are provided with neurofeedback on their arousal levels. The brain-sensing headband converts brain activity to gradations in the nature environment that is shown on the Ipad. When the players' mind is calm, the environment shows calm and settled winds, but winds will pick up and blow when the players' mind becomes active.

DayDream (developed by Gainplay Studio, Utrecht, The Netherlands) is a meditative experience that incorporates neurofeedback with a MindWave headset. Players play on a laptop, and when they start playing they see a valley during wintertime. The basic principles of *DayDream* are similar to those of *Muse*, the seasons of the valley will transform according to brain activity. When players remain calm, they are able to change the season to spring and summer and see animals wandering the valley.

Wild Divine (developed by Wild Divine, Las Vegas, Nevada) are played on a laptop and consisted of the *Minigames of Wild Divine* and



Game 1: *Muse*



Game 2: *DayDream*

Game 3: *Wild Divine Games*

FIGURE 2 Screenshots of the three game-based interventions: *Muse*, *DayDream* and *Wild Divine*

Journey to the Eagle Mountain. Both the *Minigames* and *Eagle Mountain* monitor the players' heart rate through biofeedback hardware (IomPE earlobe device). The *Minigames* are gamified relaxation tutorials that display a butterfly breathing cue to guide the player's breathing. *Eagle Mountain* is a serious game experienced through an eagle's viewpoint. The player flies free and has to catch wildlife. Breathing in coherence with the breathing cue increases success in the game: players will earn more points when they are calm. Each session, the player played one of the *Minigames*, followed by 10 minutes of *Eagle Mountain*.

2.4 | Measurements

2.4.1 | Primary outcome: physiology

Physiological recordings were conducted at baseline, post-treatment and during each intervention sessions. To obtain autonomic nervous system (ANS) parameters, the VU University Monitoring System (VU-AMS) device was used (De Geus, Willemsen, Klaver, & van Doornen, 1995; Willemsen, de Geus, Klaver, van Doornen, & Carrol, 1996). At the beginning of each intervention session, participants watched an aquatic video for 4 minutes to get recordings of their resting ANS parameters to compare with the ANS parameters during the meditation sessions (Piferi, Kline, Younger, & Lawler, 2000).

Respiratory sinus arrhythmia

To measure physiological stress regulation, we derived RSA parameters with the VU-AMS device (De Geus et al., 1995; Willemsen et al., 1996). The VU-AMS is a lightweight ambulatory device that records the electrocardiogram and changes in thorax impedance from seven electrodes placed on participants' chest and back. For a detailed description of the VU-AMS assessment procedures, see VU University Amsterdam (2015).

2.4.2 | Secondary outcomes: questionnaires

Psychopathology measurements were conducted at baseline (self-report and mentor-report), post-treatment (self-report and mentor-report) and at 1 month follow-up (self-report). The self-report measures were completed in an interview format to ensure comprehension, in particular, for participants with ID. The interviews took approximately 10 minutes and were conducted by the first author. Participants received a 15 euro gift cheque after the post-treatment measurement (they were informed about this gift check after they initially agreed to take part in the study).

User evaluations

Participants rated the items "This is important for me," "I liked today's session" and "Satisfaction with the game" on a scale of 1 to 10.

Post-traumatic symptoms

Self-reported and mentor-reported post-traumatic stress were measured using the total scores of the CRIES-13 (Verlinden et al., 2014). This questionnaire has 13 four-point items that compose the subscales "intrusion," "avoidance" and "hyperarousal." The CRIES-13 has good reliability and validity (Verlinden et al., 2014).

Depression, anxiety and stress

Self-reported depression, anxiety and stress were examined with the subscale scores "depression," "anxiety" and "stress" of the Depression Anxiety Stress Scales (DASS-21; De Beurs, Van Dyck, Marquenie, Lange, & Blonk, 2001; Lovibond & Lovibond, 1995). The DASS-21 consists of 21 four-point items. Reliability and validity of the DASS-21 are good, and internal consistency of the subscales is excellent (De Beurs et al., 2001).

Aggression

Self-reported aggression was measured with the Reactive Proactive Questionnaire (RPQ; Cima, Raine, Meesters, & Popma, 2013; Raine et al., 2006). This questionnaire consists of 23 three-point items and is composed of the subscales "proactive aggression" and "reactive aggression." The RPQ has good reliability and validity for the total questionnaire, and both subscales have good internal consistency (Cima et al., 2013).

2.5 | Analyses

All data are reported via descriptive statistics (mean and SD). The RSA data were positively skewed (skewness = 2.04, SE = .13, $P < .01$) and were $\log^{10}$ transformed to obtain normal distributions (Houtveen, Rietveld, & De Geus, 2002). To explore effects on RSA data that were measured each intervention session (in total, 355 segments of RSA recordings were used for this study), the nonparametric Wilcoxon Signed Rank test and a repeated measures mixed-model were conducted, controlling for clustering of data. Outcome data on psychopathology are based on the baseline and post-treatment measurements of the completers-only sample (N = 12). Due to our small sample size, we calculated RCIs as $(X_2 - X_1)/SE_{diff}$ or $(X_{FU} - X/SE_{diff})$ (cf, Zalta et al., 2016) to determine if any observed changes represented clinically significant change, as recommended by Jacobson and Truax (1991). Reliable change was determined with α set at .05 (two-tailed), which requires a 1.96 or −1.96 change in performance.

3 | RESULTS

3.1 | Participant demographics

The sample consisted of 15 adolescents (9 males, 6 females; mean age = 14.46, SD = 2.40) with clinical levels of post-traumatic symptoms. Nine participants were diagnosed with an ID. Average IQ scores were 86.69 (SD = 13.79) for the total sample, 94.00 (SD = 13.79) for participants without ID and 80.43 (SD = 14.73) for participants with ID. All participants were diagnosed with psychiatric disorders, most commonly reactive attachment disorder (n = 9), oppositional defiant disorder (n = 6), attention deficit disorder (n = 5), post-traumatic stress disorder (n = 4) and autism (n = 3). Comorbidity was high, with 11 participants (73.3%) diagnosed with at least two disorders. There was

participant dropout at post-test (n = 4) and at follow-up (n = 6; see Figure 1 for more detailed information).

3.2 | RSA

RSA outcomes are presented in Table 1. In all conditions, meditation RSA levels were higher compared to resting RSA levels, with medium to large effect sizes (Cohen, 1988). There was no difference between conditions in change in RSA levels (F [3, 101] = .27, P = .847).

3.3 | User evaluations

See Table 2 for user evaluations. *Muse* received the highest ratings on all outcomes, and in particular for "satisfaction with the game" with a rating of 8.42 out of 10, compared with a 7.07 and a 5.53 out of 10 for *Daydream* and *Wild Divine*, respectively.

3.4 | Psychopathology

Descriptive statistics on post-traumatic symptoms, depression, anxiety, stress and aggression are shown in Table 3. Table 4 reports participant RCIs from baseline to post-treatment and from baseline to follow-up. Overall, outcomes on stress demonstrated the most robust results with 33.3%-100% of participants showing reliable improvement and none of the participants showing reliable worsening. Among *Muse* participants, 100% showed reliable improvements in self-reported and mentor-reported post-traumatic symptoms and self-reported anxiety and stress at post-treatment and follow-up. For depression and aggression, these rates ranged 40%-80%, other participants remained stable. Participants who played *Daydream* or *Wild Divine* showed inconsistent progression. Only one *Daydream* participant showed reliable improvement in post-traumatic symptoms, others remained stable. Stress and anxiety improvement rates ranged 33.3%-50%, other participants remained stable. For depression and aggression, improvement rates ranged 33.3%-100%, but there were also participants that deteriorated. Outcomes on post-traumatic symptoms for participants who played *Wild Divine* were inconsistent: although all participants themselves reported reliable improvement, their mentor reports showed worsening of symptoms. Improvement rates for stress and aggression ranged 33.3%-66.7%, others remained stable. For anxiety, outcome changes were equally divided among improvement (33.3%), stability (33.3%) and decline (33.3%), and for depression, outcomes showed no reliable change at all.

4 | DISCUSSION

This pilot study evaluated three game-based meditation interventions that all utilize biofeedback or neurofeedback to reinforce youth's stress regulation abilities. Notably, all three interventions were able to result in physiological improvement, measured as youth's RSA during meditation. This suggests that all interventions have potential for the treatment of traumatized youth in residential care. Although results should be considered explorative and as a first step to evaluate game-based meditation interventions for traumatized youth, initial outcomes are promising.

User evaluations regarding participants' perceived importance and enjoyment of the intervention sessions were most positive for *Muse*. User satisfaction with the game was high with an average rating of 8.42 out of 10 for game satisfaction and there were no dropouts. This indicates that this form of interventions forms a novel strategy to uniquely engage and intrinsically motivate youth (Granic et al., 2014). This is critical as youths motivation is a key predictor of treatment effectiveness (Harder et al., 2012) and youth in residential care usually lack treatment motivation (Van Binsbergen, 2003). In the other intervention conditions, two participants quit study participation because they did not like the intervention (*Daydream*: n = 1; *Wild Divine*: n = 1). These interventions also received lower ratings on game satisfaction than *Muse*.

Out of all psychopathology outcomes, improvements in experienced stress were the most robust across all conditions. This is not surprising, as the main goal of all three interventions was to improve stress regulation. *Muse* was the only intervention that resulted in reliable improvements in post-traumatic symptoms, stress and anxiety for all participants. Although participants who played the other games also showed improvements on some outcomes, these were inconsistent: other outcomes remained stable or even showed deterioration. Surprisingly, the self-report outcomes on post-traumatic symptoms of participants who played *Wild Divine* showed reliable improvement, but their mentors reported worsening of symptoms. This inconsistency might be unrelated to the current study but due to the internalizing nature of many post-traumatic symptoms. As these problems tend to be inwardly focused and not direct observable, it might be possible that in some cases mentor-reports do not match with participants' own experience.

When we compared the three interventions, *Muse* was most positively evaluated and considered as the best fit for our high-risk, traumatized youth in residential care. Notably, none of the participants

TABLE 1 Physiological outcomes: RSA levels

	Resting RSA		RSA during meditation				
	Mean	SD	Mean	SD	*z*	*P*	*r*
Muse	1.65	.25	1.76	.18	−4.78	<.001	.61
Daydream	1.67	.20	1.81	.20	−3.67	<.001	.80
Wild Divine	2.23	.24	2.37	.13	−3.35	.001	.70

Abbreviation: RSA, respiratory sinus arrhythmia.

TABLE 2 User evaluations

	Muse (n = 5)		DayDream (n = 3)		Wild Divine (n = 3)	
	Mean	SD	Mean	SD	Mean	SD
"This is important for me"	7.27	2.48	6.32	.85	6.35	1.99
"I liked today's session"	7.82	1.67	7.25	1.57	6.30	2.98
"Satisfaction with the game"	8.42	1.22	7.07	1.40	5.53	4.01

who played *Muse* dropped out. This suggests high acceptability, which is promising as attrition rates for traditional trauma-focused interventions range between 35% and 40% (Boyd et al., 2018).

4.1 | Strengths and limitations

Traumatized youth in particular may fear facing their emotions and have feelings of distrust that interfere with their ability to fully engage in therapy (Cohen et al., 2012; Greenwald, 2009). The game-based meditation interventions in this study did not require youth to talk about their past. Youth are not confronted with traumatic memories nor with their emotions regarding these events. This makes these interventions particularly suitable as early trauma intervention when they are in need of treatment but lack stability or motivation for traditional trauma treatment.

This pilot study was conducted among traumatized youth in residential care. We did not hold on to commonly used exclusion criteria such as a minimal IQ-score, comorbid disorders, medication use or other forms of treatment (other than trauma-focused treatment). Our sample thus reflects the real-world population of youth in our residential institutions and results require minimal translation for implementation in residential institutions. Another strength is the inclusion of varying behavioural measures, including more objective forms of experimental assessment as well as observational questionnaires, providing a basis to assess improvement in both therapy and real-life context. Also, our follow-up measurement was informative regarding potential long-term intervention effects.

We are aware that there are also limitations to this study. First, as mentioned before, with only 15 participants, our sample was very small. Of these 15 participants, 11 participants have completed the

TABLE 3 Outcomes on psychopathology: descriptive statistics

	Baseline		Post-treatment			Follow-up		
	Mean	SD	Mean	SD	n	Mean	SD	n
Muse								
Post-traumatic symptoms								
Self-report	35.83	10.25	15.83	17.41	5	18.80	18.35	4
Mentor-report	32.84	14.46	20.00	10.07	4	N/A	N/A	N/A
Depression	7.17	4.45	3.33	4.08	5	2.80	4.66	4
Anxiety	7.17	2.93	3.00	2.83	5	4.00	5.34	4
Stress	10.21	3.74	5.83	5.12	5	4.20	6.53	4
Aggression	13.17	4.07	9.33	10.01	5	7.00	6.86	4
DayDream								
Post-traumatic symptoms								
Self-report	39.67	17.39	36.33	13.05	3	25.00	12.72	2
Mentor-report	29.67	13.32	34.67	14.29	3	N/A	N/A	N/A
Depression	7.67	5.69	4.00	5.20	3	0.00	0.00	2
Anxiety	7.67	6.03	7.00	5.00	3	4.50	3.54	2
Stress	9.33	4.50	7.00	3.81	3	4.81	1.86	2
Aggression	13.00	4.36	10.67	6.81	3	6.50	3.54	2
Wild Divine								
Post-traumatic symptoms								
Self-report	35.33	12.10	17.00	18.52	3	14.00	21.70	3
Mentor-report	29.76	7.67	32.63	11.81	3	N/A	N/A	N/A
Depression	5.00	7.81	4.67	8.08	3	5.33	8.39	3
Anxiety	4.33	5.13	5.00	7.81	3	5.00	6.93	3
Stress	7.00	6.13	4.38	7.58	3	4.67	8.09	3
Aggression	11.00	7.00	6.00	8.66	3	6.00	8.66	3

TABLE 4 RCIs for psychopathology outcomes: frequency and percentages

	Baseline to post-treatment (n = 5)			Baseline to follow-up (n = 4)		
Muse	Decline n (%)	Stable n (%)	Improved n (%)	Decline n (%)	Stable n (%)	Improved n (%)
Post-traumatic symptoms						
Self-report			5 (100%)			4 (100%)
Mentor-report			4 (100%)			
Depression		3 (60%)	2 (40%)		1 (20%)	4 (80%)
Anxiety			5 (100%)			4 (100%)
Stress			5 (100%)			4 (100%)
Aggression		1 (20%)	4 (80%)		1 (25%)	3 (75%)
DayDream						
Post-traumatic symptoms						
Self-report		2 (66.7%)	1 (33.3%)		1 (50%)	1 (50%)
Mentor-report		3 (100%)				
Depression	1 (33.3%)	1 (33.3%)	1 (33.3%)			2 (100%)
Anxiety		2 (66.7%)	1 (33.3%)		1 (50%)	1 (50%)
Stress		2 (66.7%)	1 (33.3%)		1 (50%)	1 (50%)
Aggression	1 (33.3%)	1 (33.3%)	1 (33.3%)		1 (50%)	1 (50%)
Wild Divine						
Post-traumatic symptoms						
Self-report			3 (100%)			3 (100%)
Mentor-report	2 (66.7%)	1 (33.3%)				
Depression		3 (100%)			3 (100%)	
Anxiety	1 (33.3%)	1 (33.3%)	1 (33.3%)	1 (33.3%)	1 (33.3%)	1 (33.3%)
Stress		2 (66.7%)	1 (33.3%)		2 (66.7%)	1 (33.3%)
Aggression		1 (33.3%)	2 (66.7%)		1 (33.3%)	2 (66.7%)

Abbreviations: RCI, reliable change index.

interventions they were assigned to. One participant had to be excluded because the IomPE earlobe device of *Wild Divine* was unable to monitor her heart rate. This might be due to her relatively small earlobes with three large earring holes. Another participant assigned to the *DayDream* condition had to quit study participation due to scheduling problems unrelated to the intervention and, as mentioned above, two participants quit study participation because they did not like the interventions.

Caution is warranted regarding any conclusions, in particular, regarding the user evaluation and psychopathology outcomes, as post-test measures were only completed by participants who adhered to the protocol. Thus, for *DayDream* and *Wild Divine*, outcomes are probably overstatements of their real effects. However, as this was an explorative pilot study and not a superiority study that focuses on effectiveness outcomes, we decided to use completers-only data (Schumi & Wittes, 2011) to provide an indication of the true efficacy of the interventions when these are completed as planned.

Due to the lack of a control group, no comparison was possible with improvements over time due to general effects of youths stay in residential institutions. We thus cannot attribute causality to the quantitative data outcomes. Also, we registered but did not request participants to quit ongoing treatment and medication use for ethical concerns. However, there were no differences between the conditions (all $P > .70$). This study should be seen as an exploration of the needs of high-risk traumatized youth in residential care. Given the vulnerability of these youth and novelty of the interventions that are evaluated in this study, we aimed to provide a first indication of the feasibility of the interventions before conducting a large-scale RCT.

4.2 | Implications and future directions

Game-based interventions are a novel approach to treatment that has received increased interest in the last decade (Lau, Smit, Fleming, & Riper, 2016). In residential care, two recent studies that evaluated a biofeedback videogame intervention showed high user satisfaction and reduced psychopathology outcomes (Schuurmans, Nijhof, Vermaes, Engels, & Granic, 2015; Schuurmans, Nijhof, Engels, & Granic, 2018). A neurofeedback applied game intervention targeting anxiety was as effective as CGT (Schoneveld, Lichtwarck-Aschoff, & Granic,

2018). Together with our findings, these all indicate the potential of game-based interventions for mental health care.

The interventions tested in the present study are a useful addition to traditional treatment programmes. As the game-play sessions are executed according to a standardized protocol, these could be led by trained research assistants without requiring a clinician. However, we do not want to propose these forms of intervention as a stand-alone replacement for traditional therapy, but as a beneficial addition to current treatment programs. Although not tested in this study, it would be possible to let youth play these game-based interventions independently by themselves to help them regulate their stress.

This pilot study was a first explorative step to evaluate game-based meditation interventions for traumatized youth. A first next step would be to evaluate the effectiveness of these interventions in reducing post-traumatic stress and normalizing neurobiological abnormalities. We are currently conducting a RCT to test the effectiveness of *Muse* in reducing post-traumatic stress and normalizing neurobiological stress reactivity. Although this pilot study suggests the potential of *Muse*, only by running larger and more rigorous studies we can establish evidence of its effectiveness.

5 | CONCLUSION

This pilot study shows the potential that game-based meditation interventions hold as alternative delivery models for the treatment of traumatized youth. Initial outcomes showed improvements in physiology, high user satisfaction and improvements on post-traumatic symptoms, stress and anxiety. Although findings should be considered preliminary due to our small sample size, this suggests that game-based meditation interventions form a new and engaging way to improve youths' post-traumatic stress. Further studies on this innovative form of intervention—and on *Muse* in particular—are warranted.

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