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ORIGINAL PAPER

Use of a mHealth Mobile Application to Reduce Stress in Adults with Autism: a Pre-Post Pilot Study of the Stress Autism Mate (SAM)

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Abstract

Objectives Adults with autism often need support to detect their stress and to apply adequate coping strategies for dealing with daily stress. The personalized mobile application Stress Autism Mate (SAM) is developed for and by adults with autism to detect and cope with daily life stress. SAM measures stress four times daily, generates an overview of the patients' stress level and gives personalized advice to reduce stress.

Methods With a pre-to post-treatment design, the level of perceived stress, coping self-efficacy and self-rated quality of life (QoL) was assessed at baseline (pre-test), after the four-week intervention (post-test) and after eight-week follow-up. Data was analysed using multilevel analysis taking within subject variance into account.

Results At post-test measurement, there was a significant decrease in perceived stress. At post-test as well as follow-up, a significant improvement in coping self-efficacy and improvement in self-rated QoL was seen.

Conclusions The results of this pilot study suggest that the personalized mHealth tool SAM can support adults with autism in detecting stress, improving their stress coping skills and improving their self-rated quality of life. In practice, SAM can be seen as an external stress monitor that can easily be integrated in the lives of adults with autism, to detect and cope with stress.

Keywords Autism · Perceived stress · Mental health · Mobile application · Quality of life · Adults

Autism is a life-long neurodevelopmental disorder. At least 1–3% of the world population is diagnosed with autism (Elsabbagh et al., 2012). Autism is characterized by "Persistent deficits in social communication and interaction, and restricted, repetitive patterns of behaviour, interests, or activities ", according to the 'Diagnostic and Statistical Manual of Mental Disorders' (DSM) 5 (American Psychiatric Association, 2013). The origin of autism is multifactorial, with distinct characteristics that make everyone with autism unique, resulting in clinical heterogeneity. However, a common challenge is that people with autism experience more stress compared to people without autism (Hirvikoski & Blomqvist, 2015). The fact that environments are not always adapted to people with autism, combined with their difficulty detecting their own stress signals can cause them to suddenly become overwhelmed by high stress levels. These high stress levels make it difficult to cope with stress adequately. Without effective support to detect and cope with stress, perceived stress is a factor negatively contributing to the challenges individuals with autism, unfortunately, must face in life. Adults with autism could therefore benefit from receiving support in establishing and maintaining relationships, emotion regulation, detecting daily life stress and in taking part in everyday life (Bishop-Fitzpatrick et al., 2015).

To help adults with autism improve in their ability to detect and cope with stress, it is necessary to focus on perceived, subjective stress. Perceived stress is a subjective experience, which differs from person to person. Adults with autism report higher levels of perceived stress and have lower perception of their coping abilities compared to adults without autism (Bishop-Fitzpatrick et al., 2017). In this study, perceived stress is defined as "The feelings and thoughts an individual has related to the stressfulness of their daily life and their ability to overcome these stressful events" (Phillips, 2013, p. 1453–1454). High levels of perceived stress can lead to chronic stress (Hirvikoski & Blomqvist, 2015), and may have a negative influence on

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quality of life in people with autism (Arias et al., 2018; Bishop-Fitzpatrick et al., 2018; Hong et al., 2016; Lin & Huang, 2019; Mason et al., 2018).

Since the main goal of supporting therapy for adults with autism is optimizing the independent social functioning and well-being of the patient, managing perceived stress should be a focus in treatment. However, the clinical heterogeneity in adults with autism results in diverse needs of support in behavioural and communicative functioning (Masi et al., 2017). Consequently, it is a challenge to develop an effective tool that helps people with autism to reduce perceived stress.

Regular stress management in people with autism consists of stress signalling schemes. Stress signalling schemes contain personal signals of stress (e.g. overstimulation and withdrawal in oneself) and specific actions (e.g. ask for help) to cope with stressful situations. These personal stress signals and actions are composed by the individual and their therapist. For this therapy to be successful, patients must be able to recognize their stress levels and proactively act by using stress reducing tips. People with autism, in contrast to people without autism, also need support into detecting stress signals and applying adequate stress coping mechanisms. Without this support, they can be suddenly overwhelmed by high stress levels. This contributes to the challenge of using stress-signalling schemes for reducing daily stress. As such, a new intervention in real time is needed to support adults with autism, to detect and cope with their daily perceived stress.

Over the past years, the amount of evidence suggesting the potential of technology-based interventions for supporting individuals with autism is increasing (Grynszpan et al., 2014; Miralles et al., 2020). Individuals with autism have a natural affinity for technology-based interventions because these interventions are structured, predictable and support autonomy (Carmona-Serrano et al., 2020; Valencia et al., 2019). As such, technology-based interventions may be particularly suitable for individuals with autism. Smartphone mental health (mHealth) applications (apps) have an enormous potential to improve health in people (Byambasuren et al., 2018). In 2021, around 350.000 mHealth apps were available in the app stores (Aitken & Nass, 2021; Byambasuren et al., 2018). Won Kim et al (2017) analysed the available clinical evidence for 700 mHealth apps developed for individuals with autism. The effectiveness of only a fraction of these apps was based on clinical research, which were mostly pilot studies. None of them aimed to support self-management of stress in everyday life.

To address the need for evidence-based mHealth apps to support people with autism (Moon et al., 2020), this study assessed the effectiveness of a newly developed app, the Stress Autism Mate (SAM). This study aimed to answer the following research questions: 'What is the effect of the SAM app, after four weeks of use, on (i) perceived stress, (ii) coping self-efficacy and (iii) self-rated quality of life.'

Methods

Participants

Initially, fifteen adults who met the inclusion criteria were included in the present study. The inclusion criteria were (a) being diagnosed with autism according to the DSM-5 and the guideline 'diagnostics of autism' of the Dutch Association of Psychiatry (NVVP); (b) having an IQ of above 85 according to the Wechsler Adult Intelligence Scale IV Dutch (WAIS-IV-NL), since the SAM app was developed with and for adults with an IQ above 85. All fifteen participants were receiving mental health care from Emerhese GGz Centraal, a mental health institution where all residents of the Netherlands can receive mental health care, since health insurance is mandatory in the Netherlands (Table 1).

The patient group consisted of six females and eight males with a mean age of respectively 46 years (SD 11.5) and 46 years (SD10.8), and a mean duration of treatment in months of 42.2 (SD 11.1) and 40.0 (SD 15.6). All participants were of Caucasian ethnicity.

Procedure

SAM System SAM, a mobile mHealth application, has been developed by a project group consisting of mental health researchers of the Netherlands Organization for applied scientific research (TNO), and practitioners of GGz Centraal Emerhese, Flevoland, in close alignment with the target group, fifteen patients of GGz Centraal Emerhese Flevoland.

The purpose of SAM is to support individuals with autism in stress recognition and self-management of stress in daily life, thereby improving well-being. The SAM app is easy to use, no special training is needed to use SAM. Considering the specific communication needs for adults with autism, SAM was designed to be easily customised. One can select different sets of colours for the feedback chart (i.e. traffic light colours or different shades of blue) and for the questionnaire multiple-choice options in written text or emoticons are available. SAM consists of unique features, which

Table 1 Demographic characteristics

Variable		Female ($N=6$) Mean (SD)	Male ($N=8$) Mean (SD)
Age in years		46.0 (11.5)	46.0 (10.8)
Duration of treatment in months		42.2 (11.1)	40.0 (15.6)
Race	Caucasian	100%	100%

are explained separately below. The following link provide introductory videos about the SAM app: https://youtu.be/QBrad1Si4vA Please note that the video is spoken in Dutch, but English subtitles are available.

Questionnaire

SAM sets a questionnaire four times a day with an interval of four hours. The timing of the first questionnaire is chosen by the user and it takes two minutes to complete. The questionnaire starts with what activities the user has done in the past four hours and how the user felt during these activities. This is followed by two questions about whether the user had positive thoughts and felt energized during the past four hours. The questionnaire ends with ten multiple-choice questions about stress signals experienced in the past four hours (see Table 2). These questions are based on the results of the interviews with the target group. More information about the development of SAM can be found on our website: www.stressautismmate.nl and in the appendix.

Every question-and-answer possibility in the SAM app is linked to a certain score, and the sum score corresponds to a certain stress level (i.e. no stress, little stress, stress, much stress). Based on cut-off values within the potential sum scores, the algorithm generates a report of the level of perceived stress (i.e. no stress, little stress, stress, much stress). SAM then verifies the results by asking if the measured stress level corresponds to the person's perception. When there is a discrepancy between the stress level measured by SAM and the person's own perception, this is registered on the overview page. This forms an input for the dialogue about stress signalling between the user and the practitioner or relative. In addition, we use the authentication data for the further development of SAM.

Table 2 Ten stress signalling questions SAM app collected and validated in the focus groups

Questions
Did you feel irritable?
Did you suffer from a full head?
Were you worried?
Did you have trouble concentrating?
Did you feel the need to withdraw?
Were you dreading activities on your schedule?
Did you suffer from negative thoughts?
Did you suffer from anxiety?
Were you bothered by environmental stimuli?
Did you have trouble making decisions?
Answer possibilities: 'No;' 'Yes, but not more than usual;' 'Yes, more than usual;' 'Yes, much more than usual'

Personal Coping Advice

After the algorithm has calculated a stress level, the app provides a general as well as a personalized coping advice corresponding to the level of stress, as seen in Fig. 1. The personalized advice consists of stress management tips that are pre-set by the user: while installing the app, users are asked to select preformulated tips and/or to enter their own personal tips. Examples of general preformulated coping advice are 'go for a walk,' 'do a breathing exercise' or 'listen to some music.'

Feedback Chart

At the end of every day and week, an overview of the daily stress level is generated in a feedback chart. This chart visualizes the stress level of every measurement moment and summarizes which activities contributed to feeling good or bad. By looking at the feedback chart, the user may discover stress patterns related to day-to-day activities. In this way, the user can retrospectively consider which activities or events caused or contributed to the experienced stress.

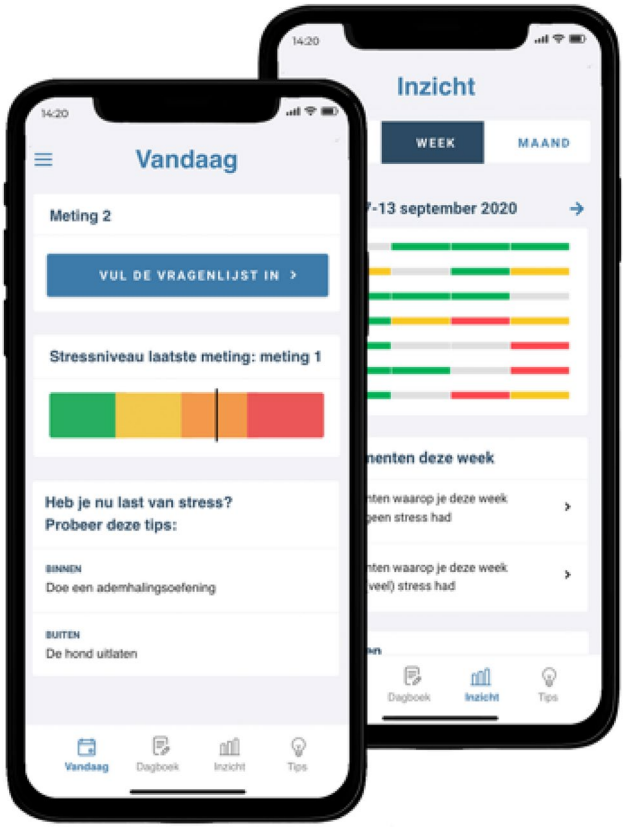

Fig. 1 Screenshots feedback chart and measured stress level

Additionally, this chart could be a focus point in therapy if the user wishes to share the results with the therapist.

Study Design This pilot study used a one-group pretest – post-test – follow-up, quasi-experimental design (Harris et al., 2006). During all phases of this study, participants continued with their regular daily activities and their usual treatment. There was no control group. This within-subject design allows each participant to potentially benefit from the intervention, potentially enhancing the feasibility of this study. The outcome parameters are (i) stress recognition and reduction, (ii) perceived stress, (iii) coping self-efficacy, and (iv) self-rated quality of life. Data was collected at three moments in time: at baseline right before the intervention (pre-test), after the four-week intervention phase (post), and after an eight-week follow-up phase (follow-up).

Baseline At baseline, just before the start of the intervention phase, the participants were invited for an individual face-to-face appointment with the researcher at a local GGz Centraal location. The baseline questionnaire was completed during this appointment. After completing the questionnaire, the participant, together with the researcher, installed the SAM app on their mobile phone and went through the settings, followed by a detailed explanation of how the SAM app works. In case a participant would not be in possession of a suitable mobile phone on which the SAM app could run, a mobile phone would be made available by the researcher. This was, however, not the case.

Intervention Phase The intervention phase lasted four weeks. This was based on the idea that a four-week period is acceptable in feasibility terms and burden on the participant. It should also be long enough for the expected effect of the intervention to occur. The expectation was that it would take users about two weeks to fully understand and integrate the SAM app into everyday life. In weeks three and four, the SAM app could influence the daily lives of the participants.

During the intervention phase, participants used SAM four times a day. At all times, a helpdesk was available for questions and technical problems. During the intervention phase, the researcher recorded that the participants completed $\geq 75\%$ of the questionnaires in the SAM app. At the end of the four-week intervention phase, the post-test questionnaire was completed in a face-to-face appointment with the researcher.

Follow-up Phase The follow-up phase lasted eight weeks. In these eight weeks, the participants did not use the SAM app. They continued with their regular daily activities and their usual treatment. At the end of the follow-up period, the final face-to-face interview took place in which the follow-up questionnaire was completed.

Measures

At all three measure moments, we used the same self-report questionnaires regarding perceived stress, coping self-efficacy and quality of life. All questionnaires were completed independently by the participants during individual face-to-face appointments at a GGz Centraal location. Characteristics regarding gender, age and duration of current treatment were collected from the electronic health record.

Stress Recognition and Reduction Part 1 consists of four items about stress recognition and reduction created by the researchers. Respectively, 1 'To what extent are you capable of recognising a high degree of stress in yourself?', 2 'To what extent are you capable of recognising a low degree of stress in yourself?' 3 'To what extent are you aware of how to reduce stress on yourself?', and 4 'To what extent are you able to actually reduce stress on yourself?' Response scale ranging from 1–10 (not capable at all, very capable).

Perceived Stress The reliable and validated Perceived Stress Scale (PSS) (Cohen et al., 1983; Hirvikoski & Blomqvist, 2015; Thoen et al., 2021) consists of ten items and is widely used to assess subjective stress in neurotypical adults as well as in adults with autism (Cronbach's $\alpha = 0.92$, McDonald's $\omega = 0.93$). An example item is 'In the last month, how often have you been upset because of something that happened unexpectedly?' Items used a five-point Likert scale anchored by "Never" and "Very often." In case of the four positively stated items, the response score had to be reversed. Higher sum scores denote higher perceived stress.

Coping Self-Efficacy The Coping Self-Efficacy Scale (CSES) (Chesney et al., 2006) is a reliable (Cronbach's $\alpha = 0.91$, McDonald's $\omega = 0.91$) and validated tool to measure the perceived coping efficacy of a person. Coping self-efficacy is defined as "one's ability to perform specific coping behaviours." (Chesney et al., 2006, p. 2) This widely used tool was chosen because it addresses specific coping abilities which are important for adults with autism. The CSES can be subdivided into three subscales: problem-focused coping, stop unpleasant emotions and thoughts, and get support from friends and family. The reliability Cronbach's Alpha for the subscales is as follows: problem-focused coping $\alpha = 0.77$, stop unpleasant emotions and thoughts $\alpha = 0.91$ and get support from friends and family $\alpha = 0.88$. An example items is 'When you are not doing well, or when you have problems, are you able to make a plan of action and follow it when confronted with a problem?' Response scale ranging from 0 to 10 (I am not able at all to I am very able).

Quality of Life Since perceived stress can negatively influence quality of life, quality of life was assessed with one

question of the World Health Organization Quality of Life (WHOQOL-BREF) questionnaire, namely 'How would you rate your quality of life?.' This item was scored with a five-point Likert scale anchored by "Very poor" and "Very good." In this case, quality of life is defined as "Individuals' perceptions of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" (World Health Organization, 1998, p. 551).

Data Analyses

The statistical analysis was done by using linear mixed effect models. The questionnaires were analysed by using the mean score for the self-developed stress recognition and reduction items, the sum score of the Perceived Stress Scale, the sum score of each subscale of the Coping Self-Efficacy Scale, and the mean score of the World Health Organization Quality of Life. The missing data is excluded from the data analysis.

In this within-subject design, all participants are their own control, so it is important to compare the questionnaire scores within everyone individually and to aggregate these results to make a statement at population level (Chen & Chen, 2014; Lillie et al., 2011; Zucker et al., 1997, 2010). Linear mixed effect models take within-subject variance into account (Hox, 2010), thereby providing a suitable analysis method for this study. For the analyses, R in combination with RStudio and the packages lme4 was used (Bates et al., 2015), lmerTest and tidyverse (Bates et al., 2015; Kuznetsova et al., 2017; Wickham et al., 2019). For each model, we used the measurement as fixed effect and the intercept or initial score as a random effect, differentiating for everyone. For the models with a significant effect of time ($p < 0.05$), we tested the assumptions of normality and heteroscedasticity of the residuals, using visualization. For the single question scales, we tested whether the use of an ordinal model using a logit-link improved assumption. As this was not the case, we decided on using a linear mixed effect model for these too.

Results

One participant dropped out during the trial due to lack of motivation to complete the questionnaires at measurement moments. Fourteen patients completed all questionnaires at pre-, post-test and follow-up. A summary of the results is presented in Table 3.

Stress Recognition and Reduction The self-reported ability to reduce stress, post-test ($\beta = 1.36$, *s.e.* $= 0.43$, $p = 0.004$) as well as follow-up, ($\beta = 1.57$, *s.e.* 0.43, $p = 0.001$) significantly

Table 3 Overview of the mean and standard deviations for baseline, post-test, and follow-up, and the multilevel results for the timeframes baseline – to – post-test and baseline – to – follow-up within the (sub)scales

	Baseline	Post-test	Follow-up	Baseline—to – post difference			Baseline—to—follow-up difference		
Variable	Mean (SD)	Mean (SD)	Mean (SD)	β	s.e	df	β	s.e	df
Stress recognition and reduction, range 0—10									
Ability to detect high stress levels	7.29 (1.54)	7.50 (2.28)	6.93 (2.06)	.21	.60	26	-.36	.60	26
Ability to detect low stress levels	5.00 (3.09)	5.07 (2.90)	5.21 (3.42)	.07	.88	26	.21	.88	26
Awareness of how to reduce stress	5.50 (1.74)	6.29 (2.13)	6.29 (2.02)	.79	.56	26	.79	.56	26
Ability to reduce stress	3.79 (1.67)	5.14 (2.38)	5.36 (2.06)	1.36**	.43	26	1.57**	.43	26
Sum score PSS, range 0 – 50									
Perceived stress	22.03 (8.94)	19.65 (7.93)	20.36 (6.51)	− 2.39*	1.09	24.16	− 1.68	1.09	24.37
Sum score CSES									
Problem focused coping Range 0–50	19.29 (8.06)	23.86 (9.09)	21.86 (9.65)	4.57*	1.95	26	2.57	1.95	26
Stop unpleasant emotions and thoughts Range 0–40	14.57 (7.65)	16.16 (6.61)	17.00 (7.18)	1.59	1.21	25.16	2.43*	1.18	25.07
Support from friends and family Range 0–20	5.71 (4.36)	9.96 (3.53)	10.00 (3.55)	4.25**	0.93	24.70	4.29**	0.91	24.49
Mean WHOQOL, range 0–5									
Estimated quality of life	1.86 (0.86)	2.36 (1.03)	2.50 (0.86)	0.50*	0.19	25.15	0.64**	0.19	25.00

Stress recognition and reduction: non-validated questions; *PSS*, Perceived Stress Scale; *CSES*, Coping Self-Efficacy Scale; *WHOQOL*, World Health Organization Quality of Life; *β*, estimate; *s.e.*, standard error; * $p \leq 0.05$; ** $p \leq 0.01$ significant higher or lower scores compared to baseline

improved compared to baseline. The effect size at post-test is medium ($d = 0.67$) and large at follow-up ($d = 0.84$). Furthermore, no significant effect was found in the ability to detect high or low stress levels or in the awareness of how to reduce stress.

Perceived Stress The ability of the participant to reduce stress post-test, ($\beta = -2.39$, *s.e.* 1.09, $p = 0.04$) significantly improved compared to baseline with a small effect size ($d = 0.29$). There was no significant effect found at follow-up compared to baseline.

Coping Self-efficacy The problem focused coping post-test, ($\beta = 4.57$, *s.e.* $= 1.95$, $p = 0.027$) significantly improved compared to baseline with medium effect size ($d = 0.53$). No significant change was found at follow-up. The capability of stopping unpleasant emotions and thoughts after follow-up, ($\beta = 2.43$, *s.e.* $= 1.18$, $p = 0.05$) significantly improved compared to baseline with a small effect size ($d = 0.33$). At this subscale, no significant effect was found between baseline and post-test. Furthermore, the capability to ask friends and family for support post-test, ($\beta = 4.25$, *s.e.* $= 0.93$, $p = 0.00$) as well as follow-up, ($\beta = 4.29$, *s.e.* $= 0.91$, $p = 0.00$) significantly improved compared to baseline. The effect size at post-test and follow up are both large, respectively $d = 1.11$ and $d = 1.23$).

Quality of Life The self-rated quality of life at post-test ($\beta = 0.50$, *s.e.* $= 0.19$, $p = 0.02$) significantly improved compared to baseline, and the self-rated quality of life after follow-up ($\beta = 0.64$, *s.e.* $= 0.19$, $p = 0.002$) significantly improved compared to baseline. The effect size both at post-test and follow up is medium, respectively $d = 0.54$ and $d = 0.75$.

Discussion

This study suggests that adults with autism could significantly better cope with stress and reduce stress after using the Stress Autism Mate (SAM) app. They experienced less stress and improved their coping-self efficacy after four-weeks of using the app (post-test). The improvement in coping self-efficacy also continued at follow-up. The participants rated their quality of life higher than before the use of SAM on both measurement points. This could indicate that participants learned to better understand and act on their stress-related behavioural patterns, which in turn improved their quality of life.

Perceived Stress As hypothesized, participants found themselves more capable of reducing stress after using SAM for four weeks and after eight weeks follow-up. Participants experienced significantly less stress after using SAM, but this improvement disappeared after the follow-up period (i.e. 8 weeks without using the app).

There are several explanations for a significant improvement after the intervention phase which then disappears at follow-up. First, this may be due to variation caused by the small sample size of this pilot study. Second, the intervention phase (i.e. 4 weeks) may not have been long enough to allow participants to independently reduce their perceived stress. For future research, it would be interesting to experiment with the length of the intervention phase to find out how long a person must use SAM for to expect an effect. Third, stress recognition may be a skill that adults with autism have difficulty learning to apply themselves. In this case, SAM may be used as an external stress measurement for extended or recurring periods to support the user as they reflect on their stress signals four times a day.

Coping Self-efficacy The overall coping self-efficacy of adults with autism improved significantly after four weeks of using SAM, and at follow-up as well. Coping self-efficacy can be divided into the three subscales of the CSES. Because there were differences between the improvement of the subscales after four-weeks using SAM versus follow-up, they will be discussed separately.

Problem Focused Coping The participants improved their problem-focused coping skills after using SAM, but the effect did not last after the eight-week follow-up. One explanation could be, as mentioned before, that adults with autism need an external 'reminder' such as the SAM app to help detect perceived stress. Also, without SAM asking the user to reflect on the perceived stress, they might no longer feel stimulated to do so.

Stopping Unpleasant Emotions and Thoughts A surprising result was that a positive effect in stopping unpleasant emotions and thoughts was seen at follow-up, but not after four-weeks of using SAM (post-test). An explanation could be that it takes time for the learning effects of SAM to cause a decrease of unpleasant emotions and thoughts. It would be interesting to investigate how long this effect of reduction of unpleasant emotions and thoughts persists after various lengths of the intervention and follow-up phase.

Seeking Support from Friends and Family A clinically relevant improvement at both measurement points was the

ability to seek help from friends and family to address practical and emotional issues. This result lends support to the idea that visualization on a graph of the level of stress experienced and/or the coping advice provided by SAM (i.e. to talk to a close relative), may make the participant and family or friends more aware of asking for help. Another contributing factor could be that the user becomes more aware of their stress signals in the first place, making it easier to talk about them with relatives.

Quality of Life The self-rated quality of life of the participants using SAM for four weeks improved significantly, directly after the intervention period but also at the endpoint of the study. The improvement in quality of life could be related to the decrease of perceived stress. Such would be in line with previous research that shows a negative effect of perceived stress on the quality of life in participants with autism (Bishop-Fitzpatrick et al., 2018; Hong et al., 2016).

Limitations and Future Research

The app was developed in collaboration with adults diagnosed with autism resulting in a personalized autism-friendly app in which the stress signalling questions are specified for adults with autism. Although this is remarkable and important, this is not enough to recommend adding this app to the support arsenal. There are also some limitations to the present study. First, the number of participants was small ($N = 14$), and no control group or control period was used. We chose to start with a pilot study because we first wanted to explore whether the app was workable at all and whether it might influence perceived stress. However, despite the small sample size, there were several noteworthy results, which is promising for future research. A control group or control period to compare the results should be used in future research. Second, the participants were already involved in the development of the app and were asked to think about perceived stress and how to measure this stress in adults with autism. This could have made the participants more aware of perceived stress in comparison to people not involved in the app development, allowing the participant to achieve more progress with SAM. However, if participants were already aware of perceived stress and how to cope with it at baseline, this could also have reduced the effect of SAM. Another point may be that the involvement of the participants in the development of the app made them very motivated to test the app resulting in a very low drop-out rate. It is possible that with regular use of the app among adults with autism, the number of dropouts will be higher. Finally, there may be common method bias due to the use of multi-item scales within the same questionnaire. This phenomenon could lead to false correlations between the measured items (Podsakoff et al., 2012). In this pilot study, however, we did not analyse correlations between multi-item scales, but change within multi-item scales questionnaires over time.

In future research, a larger trial is needed to assess the effectiveness of SAM on adults with autism. In such a trial, a single case experimental design (SCED) incorporating a pre-control period could be used, and to avoid any history bias, the participants should be randomly divided into groups who will start on different periods in time.

The positive results also give new innovative ideas. Since stress occurs frequently in psychiatric disorders and can have a disastrous effect, variants of the SAM app could be helpful for other target groups as well, such as adults with an anxiety disorder. Furthermore, at this moment SAM can estimate the participants' stress levels only retrospectively. It would be interesting to develop a function to measure real-time stress in adults with autism and link this to SAM to give stress-reducing advice whenever acute stress occurs.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41252-022-00304-3.

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Author Contribution KH: executed the study, assisted with the data analyses, and wrote the paper. YR and IN collaborated with the design, execution of the study and writing of the study. PH: collaborated in the writing and editing of the final manuscript. All co-authors have seen and agree with the contents of the manuscript.

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Declarations

Ethics Approval This study was approved by the medical ethics review committee Brabant (reference number: NL70071.028.19/P927).

Informed Consent All individuals consented to participation in the study.

Conflict of Interest The authors declare no competing interests.

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References

Aitken, M., & Nass, D. (2021). Digital health trends 2021. *Iqvia Institute for Human Data Science,* 2–14.

American Psychiatric Association. (2013). Autism spectrum disorder. *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Arias, V. B., Gomez, L. E., Moran, M. L., Alcedo, M. A., Monsalve, A., & Fontanil, Y. (2018). Does quality of life differ for children with autism spectrum disorder and intellectual disability compared to peers without autism? *Journal of Autism and Developmental Disorders, 48*(1), 123–136. https://doi.org/10.1007/s10803-017-3289-8

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects areas models using lme4. *Journal of Statistical Software, 67*(1). https://doi.org/10.18637/jss.v067.i01

Bishop-Fitzpatrick, L., Mazefsky, C. A., & Eack, S. M. (2018). The combined impact of social support and perceived stress on quality of life in adults with autism spectrum disorder and without intellectual disability. *Autism, 22*(6), 703–711. https://doi.org/10.1177/1362361317703090

Bishop-Fitzpatrick, L., Mazefsky, C. A., Minshew, N. J., & Eack, S. M. (2015). The relationship between stress and social functioning in adults with autism spectrum disorder and without intellectual disability. *Autism Research, 8*(2), 164–173. https://doi.org/10.1002/aur.1433

Bishop-Fitzpatrick, L., Smith DaWalt, L., Greenberg, J. S., & Mailick, M. R. (2017). Participation in recreational activities buffers the impact of perceived stress on quality of life in adults with autism spectrum disorder. *Autism Research, 10*(5), 973–982. https://doi.org/10.1002/aur.1753

Byambasuren, O., Sanders, S., Beller, E., & Glasziou, P. (2018). Prescribable mHealth apps identified from an overview of systematic reviews. *NPJ Digital Medicine, 1*, 12. https://doi.org/10.1038/s41746-018-0021-9

Carmona-Serrano, N., Lopez-Belmonte, J., Cuesta-Gomez, J. L., & Moreno-Guerrero, A. J. (2020). Documentary analysis of the scientific literature on autism and technology in web of science. *Brain Sciences, 10*(12), 985. https://doi.org/10.3390/brainsci10120985

Chen, X., & Chen, P. (2014). A comparison of four methods for the analysis of N-of-1 trials. *PLoS ONE, 9*(2), e87752. https://doi.org/10.1371/journal.pone.0087752

Chesney, M. A., Neilands, T. B., Chambers, D. B., Taylor, J. M., & Foolkman, S. (2006). A validity and reliability study of the coping self-efficacy scale. *British Journal of Health Psychology, 11*, 421–437.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A Global measure of perceived stress. *Journal of Health and Social Behavior, 24*, 385–396.

Elsabbagh, M., Divan, G., Koh, Y. J., Kim, Y. S., Kauchali, S., Marcin, C., Montiel-Nava, C., Patel, V., Paula, C. S., Wang, C., Yasamy, M. T., & Fombonne, E. (2012). Global prevalence of autism and other pervasive developmental disorders. *Autism Research, 5*(3), 160–179. https://doi.org/10.1002/aur.239

Grynszpan, O., Weiss, P. L., Perez-Diaz, F., & Gal, E. (2014). Innovative technology-based interventions for autism spectrum disorders: A meta-analysis. *Autism, 18*(4), 346–361. https://doi.org/10.1177/1362361313476767

Harris, A. D., McGregor, J. C., Perencevich, E. N., Furuno, J. P., Zhu, J., Peterson, D. E., & Finkelstein, J. (2006). The use and interpretation of quasi-experimental studies in medical informatics. *Journal of the American Medical Informatics Association, 13*(1), 16–23. https://doi.org/10.1197/jamia.M1749

Hirvikoski, T., & Blomqvist, M. (2015). High self-perceived stress and poor coping in intellectually able adults with autism spectrum disorder. *Autism, 19*(6), 752–757. https://doi.org/10.1177/1362361314543530

Hong, J., Bishop-Fitzpatrick, L., Smith, L. E., Greenberg, J. S., & Mailick, M. R. (2016). Factors associated with subjective quality of life of adults with autism spectrum disorder: Self-report versus maternal reports. *Journal of Autism and Developmental Disorders, 46*(4), 1368–1378. https://doi.org/10.1007/s10803-015-2678-0

Hox, J. J. (2010). *Multilevel analysis: Techniques and applications* (2nd ed.). Routledge. https://doi.org/10.4324/9780203852279

Kim, J. W., Nguyen, T.-Q., Gipson, S.Y.-M.T., Shin, A. L., & Torous, J. (2017). Smartphone apps for autism spectrum disorder—Understanding the evidence. *Journal of Technology in Behavioral Science, 3*(1), 1–4. https://doi.org/10.1007/s41347-017-0040-4

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*(13). https://doi.org/10.18637/jss.v082.i13

Lillie, E. O., Patay, B., Diamant, J., Issell, B., Topol, E. J., & Schork, N. J. (2011). The n-of-1 clinical trial: The ultimate strategy for individualizing medicine? *Personalized Medicine, 8*(2), 161–173. https://doi.org/10.2217/pme.11.7

Lin, L. Y., & Huang, P. C. (2019). Quality of life and its related factors for adults with autism spectrum disorder. *Disability and Rehabilitation, 41*(8), 896–903. https://doi.org/10.1080/09638288.2017.1414887

Masi, A., DeMayo, M. M., Glozier, N., & Guastella, A. J. (2017). An overview of autism spectrum disorder, heterogeneity and treatment options. *Neuroscience Bulletin, 33*(2), 183–193. https://doi.org/10.1007/s12264-017-0100-y

Mason, D., McConachie, H., Garland, D., Petrou, A., Rodgers, J., & Parr, J. R. (2018). Predictors of quality of life for autistic adults. *Autism Research, 11*(8), 1138–1147. https://doi.org/10.1002/aur.1965

Miralles, I., Granell, C., Diaz-Sanahuja, L., Van Woensel, W., Breton-Lopez, J., Mira, A., Castilla, D., & Casteleyn, S. (2020). Smartphone Apps for the treatment of mental disorders: Systematic review. *JMIR mHealth and uHealth, 8*(4), e14897. https://doi.org/10.2196/14897

Moon, S. J., Hwang, J., Hill, H. S., Kervin, R., Birtwell, K. B., Torous, J., McDougle, C. J., & Kim, J. W. (2020). Mobile device applications and treatment of autism spectrum disorder: A systematic review and meta-analysis of effectiveness. *Archives of Disease in Childhood, 105*(5), 458–462. https://doi.org/10.1136/archdischild-2019-318258

Phillips, A. C. (2013). Perceived stress. *Encyclopedia of Behavioral Medicine*, 1453–1454. https://doi.org/10.1007/978-1-4419-1005-9_479

Podsakoff, P. M., MacKenzie, S. B., & Podsakoff, N. P. (2012). Sources of method bias in social science research and recommendations on how to control it. *Annual Review of Psychology, 63*, 539–569. https://doi.org/10.1146/annurev-psych-120710-100452

Thoen, A., Steyaert, J., Alaerts, K., Evers, K., & Damme, T. V. (2021). A systematic review of self-reported stress questionnaires in people on the autism spectrum. *Review Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s40489-021-00293-4

Valencia, K., Rusu, C., Quinones, D., & Jamet, E. (2019). The impact of technology on people with autism spectrum disorder: A systematic literature review. *Sensors, 19*(20), 4485. https://doi.org/10.3390/s19204485

Wickham, H et al., (2019). Welcome to the Tidyverse. *Journal of Open Source Software, 4*(43), 1686. https://doi.org/10.21105/joss.01686

World Health Organization. (1998). *Programme on mental health: WHOQOL user manual, 2012 revision*. World Health Organization. https://apps.who.int/iris/handle/10665/77932

Zucker, D. R., Ruthazer, R., & Schmid, C. H. (2010). Individual (N-of-1) trials can be combined to give population comparative treatment effect estimates: Methodologic considerations. *Journal of Clinical Epidemiology, 63*(12), 1312–1323. https://doi.org/10.1016/j.jclinepi.2010.04.020

Zucker, D. R., Schmid, C. H., McIntosh, M. W., D'Agostino, R. B., Selker, H. P., & Lau, J. (1997). Combining single patient (N-of-1) trials to estimate population treatment effects and to evaluate individual patient responses to treatment. *Journal of Clinical Epidemiology, 50*(4), 401–410. https://doi.org/10.1016/s0895-4356(96)00429-5

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