Psychotherapy 2.0 - Application Context and Effectiveness of Sensor Technology in Psychotherapy with Children and Adolescents: a Systematic Review

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Abstract

Background: E-mental health applications have been increasingly used in the psychotherapeutic care of patients for several years. State-of-the-art sensor technology could be used to determine digital biomarkers for the diagnosis of mental disorders.

Objective: Furthermore, by integrating sensors into treatment, relevant contextual information (e.g. field of gaze, stress levels) could be made transparent and improve the treatment of people with mental disorders. An overview over studies on this approach would be useful to provide information about the current status quo.

Methods: A systematic review of the use of sensor technology in psychotherapy for children and adolescents was conducted with the aim of investigating the use and effectiveness of sensory technology in psychotherapy treatment. Five databases were searched for studies ranging from 2000 to 2023. The study was registered by PROSPERO (CRD42023374219), conducted according to Cochrane recommendations and used the PRISMA reporting guideline.

Results: Of the 38.560 hits in the search, only 11 publications met the inclusion criteria, including 3 RCTs, 7 pilot studies and a pre-registered study with a total of 257 subjects. The study population consisted of children and adolescents aged 6 to 19 years with mental disorders such as OCD, anxiety disorders, PTSD, anorexia nervosa and autism. The psychotherapy methods investigated were mostly cognitive behavioral therapy (face-to-face contact) with the treatment method of exposure for various disorders. In most cases, ECG, EDA, eye-tracking and movement sensors were used to measure vital parameters. The heterogeneous studies illustrate a variety of potential useful applications of sensor technology in psychotherapy for adolescents. In some cases, the feasibility of the sensor-based therapy approach has been proven.

Conclusions: Sensors might enrich psychotherapy in different application contexts. However, so far there is still a lack of further randomized controlled clinical studies that provide reliable findings on the effectiveness of sensory therapy in psychotherapy for children and adolescents. This could stimulate the embedding of such technologies into psychotherapeutic process. Clinical Trial: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023374219, identifier [CRD42023374219].

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Systematic Review

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Abstract

Background: E-mental health applications have been increasingly used in the psychotherapeutic care of patients for several years. State-of-the-art sensor technology could be used to determine digital biomarkers for the diagnosis of mental disorders. Furthermore, by integrating sensors into treatment, relevant contextual information (e.g. field of gaze, stress levels) could be made transparent and improve the treatment of people with mental disorders. An overview over studies on this approach would be useful to provide information about the current status quo.

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Conclusion: Sensors might enrich psychotherapy in different application contexts. However, so far there is still a lack of further randomized controlled clinical studies that provide reliable findings on the effectiveness of sensory therapy in psychotherapy for children and adolescents. This could stimulate the embedding of such technologies into psychotherapeutic process.

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Keywords: psychotherapy[1], digitalization[2], mental disorders[3], sensor technology[4], sensor-based psychotherapy[5], physiological sensors[6], treatment[7], children and adolescents[8]

Introduction

Digitalization has opened up new possibilities in the field of psychotherapeutic treatment of patients [1]. This development includes digital forms of intervention such as e-mental health apps and video

psychotherapy, which can expand existing care options to address the increasing need for therapy of patients and, at the same time, utilize resources effectively [2]. Meta-analyses showed, for example, that internet-based psychotherapy via video might be as effective for adults [3-5] and adolescents [6-8] as traditional face-to-face therapies. Other developments in psychotherapy include the use of wearable sensor technology such as wrist-worn wearables, which make it possible to record patients' biological data such as stress reactions and monitor physiological responses to therapeutic interventions in real time [9].

The average age of onset of mental disorder is 14.5 years [10] and early intervention can prevent chronification of the illness [11]. These advances in digitalization may therefore be particularly important in the treatment of adolescents, as they grow up in a digitalized world and have a high affinity for digital technologies [12]. Studies confirm a high level of satisfaction among adolescent patients and their parents with digital treatment approaches [13,14]. In recent decades, research on the use of technology in psychotherapy has increased considerably [15]. Especially in the wake of the Covid-19 pandemic, there has been a rapid increase in the use of digital technologies in psychotherapeutic treatment [45,46]. To date, however, there has been a lack of systematic evaluations of this novel approach.

Generally, sensor-based measurement techniques require minimal patient engagement and utilize modern, unobtrusive, wearable technology that can be seamlessly integrated into daily life [16]. These devices, which are often worn on the body, are able to continuously collect data via sensors without interrupting routine activities. They help track various aspects of a person’s physical health and provide initial insights into basic psychological states, such as fluctuations in stress levels and composure [17]. A recent review highlighted the existence of 438 unique wearable devices, typically worn on the wrist, head, chest, ear or arm [18]. These devices are designed to monitor various physiological indicators, including heart rate (HR) [19], heart rate variability (HRV) [20], body temperature [21], respiratory rate [22], blood oxygen levels [23] and skin conductance [24]. In addition, advances in mobile neuroimaging – such as functional near-infrared spectroscopy [25], wearable EEG caps [26], and mobile recording of brain activity [27] – facilitate the study of brain activity under real-life conditions. An exceptional category within ambulatory technology is smartphones, which, equipped with numerous sensors, can analyze geolocation, app usage, and social media interactions to infer behavioral patterns and perform digital phenotyping [28].

In psychotherapy, wearable sensors have been used in the treatment process for adult patients with various disorders and different functions. In the diagnosis of mental disorder [29,30], passive tracking can be used to record specific markers and the severity of a disorder [31-34], e.g. by recording the movement behavior of depressed patients through the GPS tracker and the integrated pedometer or the contact behavior of anxiety patients by making phone calls or sending text messages. Sensors can be used to monitor mood states of affective disorders [32,38] or to investigate the relationship between depression and circadian rhythm disruption in patients [35] using an actigraphy device. Information resulting from sensors can also be used to assess the risk of relapse in major depressive disorder [36,37] by using digital questionnaires via smartphone in combination with measuring the patient's activity behavior to determine the risk of relapse.

Initial results from pilot studies on the use of sensors in psychotherapy are also available for adolescents – however, proof of efficacy is still pending [39,40]. Sensors have been used in adolescents in a similar way to adults for different mental disorders and with different goals: Using a wearable sensor attached to the foot, the movements and movement complexity of young children at risk of autism [43] can be recorded and compared with autism-specific movement patterns. In adolescent patients, a pilot study has investigated whether physiological data and obsessive-

compulsive symptoms [42] or depression symptoms [41] can be collected to predict the severity of the disorder using a machine learning approach. A planned review on obese adolescents [44] aims to investigate sensor-based accelerometers that increase physical activity and reduce obesity in patients.

Eye-tracking glasses have already been used in a large number of studies with adult and adolescent patients to determine physiological markers. In addition to studies on attention distortion in anorexia nervosa with the aim of measuring the eye fixation duration presentation of food stimuli [47-49], the distorted perception of one's own body image [50], the increased concentration on the body instead of faces [60] and the avoidance of eye contact [61] in comparison to non-anorexic patients, visual adherence to certain foods in binge eating disorder [51] could be demonstrated with the help of eye-tracking glasses.

HR and HRV are also often investigated as a bio signal in mental disorder [57]. Previous studies have used ECG sensors to determine biological correlates of mental disorder in adults and adolescents, such as in depression [62,63,72], anxiety disorder [64], schizophrenia and anorexia [73], and autism [65,71]. For example, Chalmers et al. [64] specify in a meta-analysis that patients with an anxiety disorder have a lower HRV than healthy control subjects. Similar results were concluded by Hartmann et al. [63] in a study on heart rate variability in depression. The research team found that there were differences in HRV between depressed and healthy subjects and that the severity of depression symptoms correlated with changes in HRV parameters [63].

Further, ECG may be used to predict the risk of suicide in various psychiatric disorders [66], as a marker for stress reactions [67], or as a prognosis for treatment success in PTSD [68].

Moreover, sensors can also be actively used as a component in the psychotherapeutic treatment of patients and make previously invisible processes visible. In previous studies, cognitive behavioral therapy methods were used to record the heart rate and heart rate variability of patients with PTSD [74], fear of flying [75], obsessive-compulsive disorder [76] and agoraphobia [77] in parallel to psychotherapy with exposures in order to investigate physiological arousal during treatment. Raghav et al. [78] combined the performance of virtual exposure sessions (VRET) in patients with dental phobia with the recording of heart rate to investigate the subjective tension of patients during virtual exposure.

Despite the ongoing digitalization in psychotherapy combined with the use of state-of-the-art sensor technology and promising results in adults, research on sensor-based psychotherapy, in which sensors are actively integrated into the psychotherapeutic process, is limited in children and adolescents. In this systematic review, we summarize the current state of research on this topic and provide an overview of applied technologies, methods, results, and the effectiveness of previous studies to facilitate the continuation of research in this area.

Questions and Objectives

The aim of this systemic review is to examine the current state of research on the use and effectiveness of sensory therapy in psychotherapy for children and adolescents. Existing research findings will be systematically analyzed and processed based on the following questions: Which (1) type of sensory technology is used with which (2) goal, for which (3) disorder, for which (4) age group of patients? How (5) effective is sensor-based psychotherapy?

Methods

Protocol and Registration

The systematic review was registered with PROSPERO under the registration number CRD42023374219 [79]. To ensure the quality of the review, the Preferred Reporting Items For Systematic Reviews and Meta-Analysis (PRISMA-P) and a PRISMA flowchart [80] were used. The complete checklist for this review can be found in the Appendix.

Selection Criteria

The PICO(S) scheme [81] was used to define the research question and the inclusion and exclusion criteria. All kinds of studies were included that (1) investigated children and/or adolescents with an average age ≤18 years, (2) had a mental disorder diagnosed according to DSM-V [82] or ICD-10 [83], (3) conducted a psychotherapeutic guideline treatment in face-to-face contact or online via video, or (4) used a sensor worn on the body and integrated into the therapy process. Hereby a sensor was defined as any type of technical device that measures vital signs or movements. The outcome (5) was defined as the use, scope and aim of the sensor application in psychotherapy in order to compare the different studies with each other, provided that proof of efficacy was available. The included studies had to be available in (6) full text and in (7) English or German.

Studies were excluded if (1) the patients were on average ≥18 years old, (2) the sensor was only used for pre- and post-treatment measurements as a part of diagnostic process only, (3) or only one sensor application was used, e.g. a stress test with a sensor, was conducted, or if a single intervention, e.g. exposure to psychotherapy, was assessed without the intervention being embedded in psychotherapy. The exclusion criteria were chosen because a solid research base on the use of sensors for pre- and post-measurement as well as biofeedback and neurofeedback are already available. We also excluded studies that (4) included biofeedback or neurofeedback or studies that (5) only used virtual reality as a treatment method without an additional sensor. Articles for which full text could not be obtained and other reviews were also excluded.

Systematic Literature and Coding

The systematic literature search was conducted using a predefined search strategy, in the months of November and December 2023, in the electronic databases PubMed (MEDLINE), Web of Science (Ovid), Cochrane Library, APA PsycInfo (EBSCOhost) and PSYNDEX (EBSCOhost). Each database was searched for articles published between 2000 and 2023. The search strategy of the review consisted of 3 search components. We searched for a psychotherapeutic treatment, a mental disorder, and a sensor. For the search, generic terms of the search components were used. In addition to the term "psychotherapy", similar terms such as treatment, CBT, and iCBT were also included. For "mental illness", specific mental disorders such as anxiety or obsessive-compulsive disorder, post-traumatic stress disorder, ADHD, etc. were also searched for. The "sensor" used was searched for using terms such as sensor-based, sensor-supported, technology, wearable, or by types of sensors in the form of ECG chest straps, eye-tracking glasses, EDA sensors, motion sensors, or by the variable to be measured such as stress, tension or movement. The search terms were searched in titles (ti), abstracts (ab), all fields (af) and MeSh terms. Boolean operators such as "and" and "or" were used to combine the search terms. “Grey literature” was searched for using various access methods [84] and included to avoid a selection bias. In addition to the manual search via the Google Scholar search engine, the authors of the included papers were contacted by e-mail to obtain further unpublished literature and additional searches were carried out in literature databases for grey literature. A detailed documentation of the literature search strategies used in the databases can be found in Table 1 in the Appendix.

Study Selection and Data Extraction/Coding

All search results were managed centrally in a library in the literature management program EndNoteTM 20 [85]. After checking the duplicates, titles and abstracts were screened for predefined inclusion criteria and the availability of the full texts was ensured [86]. The articles potentially selected for the systematic review were uploaded to Rayyan [87] and assessed by two independent reviewers A.K.A. and A.P.

The agreement in terms of interrater reliability was 98.7 %. All studies that did not meet the inclusion criteria based on the assessments of the two reviewers were excluded. In case of discrepancies, the studies in question were discussed and, if necessary, a third reviewer was involved in the discussion. A flow diagram of the literature search is given in Figure 1.

The data from the studies were transferred to a web-based extraction form. The aim of the extraction was to structure the data and ensure the consistency of the extraction process. Where available, information such as publication details (study name, authors, year), study design and methods (population, number of therapy hours, sensor used), sample characteristics (number of subjects, age, gender), aim of the sensor used and outcome were extracted.

Risk of Bias and Quality of Evidence Assessment

The Cochrane tool for assessing risk of bias in randomized trials, RoB2, was used to assess the quality of the included randomized clinical trials [88]. Biases in sample allocation (selection bias), treatment (performance bias), recording of results (detection bias), group differences (attrition bias) and selective reporting of positive trial results (reporting bias) were assessed in five different domains [89].

For single-arm, non-randomized studies, such as feasibility studies, there is currently no standardized assessment tool for evaluating the quality of the risk of bias [90]. For this reason, the included feasibility studies were analyzed descriptively based on the Cochrane Collaboration's tool for non-randomized studies, ROBINS-I [91]. Biases reported included selection of study participants, classification of interventions, deviation from intended interventions, missing data from, e.g., initially included individuals, measurement of outcome data and selection of reported outcomes. Biases are assessed for RCTs with low, high or unclear risk. Robvis [92] was used to illustrate the assessment of risk of bias of RCTs. The quality assessment of the studies was done by two persons A.K.A and L.S., independently of each other.

Data Synthesis

Due to the small number of included studies, no meta-analytical aggregation of the data was performed. Instead, a systematic narrative data synthesis was chosen as the form of analysis [93]. The aim of narrative synthesis is to systematically review and summarize the results of multiple studies, develop a theory, produce a preliminary synthesis of the results, examine the relationship of the data to each other, and assess the robustness of the synthesis using words and text [94]. The coded text parts were first organized into main categories (Authors, Country, Disease, Sample, Intervention, Sensor, Aim, Result). Subsequently, the extracted data were analyzed in relation to each other in the context of the study design, with a focus on the sensor-based therapy intervention [95]. The included studies, the analyzed variables and main categories are presented in Table 2.

Results

Study Selection

A total of 38.560 articles were identified in the initial search. After excluding duplicates, 30.883 studies were reviewed for inclusion in the study. 30.684 articles were excluded because they did not meet the inclusion criteria. 149 full-text articles were analyzed in more detail, resulting in 10 studies

and 1 pre-registration from the "grey literature search" being included in the systematic review. Two articles reported on the same study, so only one of the two was included in the analysis. See Figure 1 for the PRISMA flow diagram.

---------- Figure 1 ----------

Characteristics of the Studies Included in the Review

All characteristics of the included studies, divided into different categories, are shown in Table 2. The studies were published between 2017 and 2023 and the majority were conducted in Europe [96,97,98,99,100] and the USA [101,102,103,104]. Most of the studies were pilot or feasibility studies, without randomization [96,97,98,99,100,102]. Only 3 of the included studies were RCTs [110,112,113] and one pre-registration for an ongoing study could be identified via the "grey literature search" [105].

---------- Table 2 ----------

Study Population

A total of 257 subjects (53% male) aged between 6 and 19 years with an average age of 12.79 years took part in the nine included and completed studies. The sample size of the studies varied between 5 and 71 participants. Two studies each treated children and adolescents with an autism spectrum disorder [98,104], an anxiety disorder [97,102] and a post-traumatic stress disorder [101,103]. One study each described the treatment of children and adolescents with anorexia nervosa [96], borderline personality disorder [100] and obsessive-compulsive disorder [99]. The study found via the "grey literature search" was a VR-based intervention for adolescents (aged 14 years and older) with anorexia nervosa [105].

Intervention/Treatment

In 8 of the 10 studies, the treatment of children and adolescents took place in face-to-face contact [96,97,100,101,102,103,104,105]. The treatments focused on behavioral interventions in which the sensor was used during one or more exposure exercises [96,97,99,101,102,103,104,105].

Sensors used/Aim/Outcome

In the psychotherapy sessions, ECG sensors [97,98,102,103] were predominantly used to measure HR and HRV in patients or therapists, EDA skin sensors [102] to measure electrodermal activity, movement sensors [100] to measure movement synchrony or to recognize movement patterns, and VR and eye-tracking glasses [96] to identify gaze patterns or to train attentional focusing [105]. In one study each, a multimodal sensor set consisting of various sensors (ECG, eye-tracking glasses, motion sensors) [99] was used to measure and recognize stress reactions and an AI Google Glass [104] was used to train emotion recognition.

In the following section of the review, all included studies are shortly described.

In a pilot study with 23 adolescent inpatients with anorexia nervosa (M_{Age}= 15.30 years, SD = 1.29), Ascione et al. [96] investigated the effectiveness of a one-hour body-related modification task

(ABMT) with a body exposure using VR and a virtual avatar. The assessment of gaze behavior was recorded with eye-tracking glasses. The duration of fixation on weight-related body parts was significantly reduced compared to the measurement before the one-hour training session (Cohen's *d* = 0.45) and body dissatisfaction decreased in the anorexia patients (Cohen's *d* = 0.39).

In a non-randomized feasibility study, Kahlon et al. [97] examined the symptom reduction of public speaking anxiety in adolescents (M_{Age} = 14.22 years, *SD* = 0.64) in a 90-minute session in which the heart rate of the adolescents was monitored by a bracelet that recorded the heartbeat during virtual exposure as stress indicator. The physiological data showed a slight increase in heart rate during the VR exposure. In the pre-post comparison, there was a significant decrease in anxiety symptoms (Cohen's *d* = 1.53) and a constant improvement in the follow-up examination.

Lipschutz et al. [101] used data from a randomized clinical trial in children and adolescents (M_{Age} = 9.70 years, *SD* = 1.90) with PTSD by Scheeringa & Weems [138] and examined respiratory sinus arrhythmia (RSA) as a marker for stress reactivity, which was recorded using an ECG during trauma exposure as part of a 12-hour CBT treatment. PTSD symptoms decreased significantly after CBT ($F(1.46) = 74.93$, $p < .0001$) but no relation between the symptom change and pre-treatment RSA resting scores could be found ($F(1.46) = 0.53$, $p = .47$).

López-Florit et al. [98] recorded online therapy sessions of 16 Spanish male autism patients (M_{Age} = 12.50 years, *SD* = 2.99) and measured therapists' heart rate with a wireless ECG sensor during the sessions to investigate therapists' stress levels and a potential association of patients' intellectual and narrative abilities with conversation management and speaker changes in online psychotherapy sessions. It was found that patients' communicative intention was determined by their intellectual abilities ($r = 0.53$, $p = .05$). Speaker switching from therapist to participant was associated with the patient's emotional-behavioral difficulties (self-report antisocial behavior, r = 0.70, $p = .05$) and led to higher stress levels in therapists (Chi2 7.09; gl 2; $p = .05$).

McCormack et al. [102] investigated the extent to which self-reported anxiety corresponds with electrodermal activity (EDA) as an indicator of tension in children and adolescents (M_{Age} = 11.38 years, *SD* = 1.66) with an anxiety disorder by recording the physiological arousal of adolescents during the exposure sessions within a total of 8 hours of CBT treatment. Higher sympathetic arousal was associated with a poorer response to treatment ($\beta = 0.32$, $t(32) = 2.25$, $p = .032$, CI: 0.09-1.73). Thus, physiological arousal could be considered as the strongest predictor of treatment response.

In their randomized clinical trial, Shenk et al. [103] reported on the change in respiratory sinus arrhythmia, measured with an ECG sensor in a 12-hour CBT treatment of adolescents (M_{Age} = 11.79 years, *SD* = 3.08) with a PTSD diagnosis. The study investigated the effect of animal-assisted therapy as an add-on treatment to CBT compared to standard CBT and compared the effects on the adolescent patients' RSA. There was no significant difference on the average RSA amplitude in the treatment groups ($\delta 001 = 0.082$, $p = .844$)

In their pilot study, Thierfelder et al. [99] focused on five adolescents (M_{Age} = 15.20 years) with OCD to test a multimodal sensor system consisting of an ECG sensor, eye-tracking glasses and movement sensors worn by the patients during iCBT treatment to determine whether the sensors could validly record the adolescents' stress reactions during the exposure sessions. Stress and anxiety reactions could be detected by the sensors, illustrated in the ECG analysis by an increasing heart rate and a decreasing HRV as markers of psychological stress.

In their randomized clinical study, Voss et al. [104] examined a total of 71 autistic children (M_{Age} =

8.38 years, *SD* = 2.46) to determine whether training emotion recognition with AI Google Glasses at home 4 times a week, 6 minutes each, for 20 minutes, in combination with conventional CBT treatment, had a positive effect on the patients' social skills compared to adolescents without corresponding exercises with AI technology. The wearable digital intervention had a positive effect on face recognition in children with autism, so that their social behavior was demonstrably improved as a result (mean treatment effect: 4.58 points, $p = .005$, mean learning effect: -1.56 points in the ITT cohort).

Zimmermann et al. [100] determined movement synchrony using video cameras, ECG and EDA sensors in a total of 16 female borderline patients (M_{Age} = 16.6 years, *SD* = 1.50) and treating therapists by videorecording 356 hours of individual psychotherapy sessions and comparing them with pseudo-interactions. In the psychotherapy sessions, a synchrony of movement between therapist and adolescent patient could be demonstrated (Cohen's $d = 0.85$).

Maldonado et al. [105] plans to conduct a study on attention bias training in adolescent anorexia patients. A study with n = 75 adolescents, aged 14 and over, in an RCT design is planned. During the five sessions of VRET, a body expository training will be conducted in virtual reality and eye movements will be recorded via eye-tracking. The study is still ongoing, no results are available yet.

Assessment of Risk of Bias in the Studies Included in the Review

The results of the quality assessment of the ten studies included in this systematic review with regard to risk of bias are shown in Figure 2. Overall, the RCTs [101,103,104] were evaluated as having a low to medium risk of bias. Subjects were selected in all studies using predefined inclusion and exclusion criteria [101,103,104]. The randomization of participants was blinded in the RCTs, so that a low bias in the selection, inclusion of participants and allocation to the intervention can be assumed [101,103,104]. No deviations from the planned intervention of the subjects were described during the treatment in the studies [101,103,104]. The results were fully reported in two of three studies [103,104] and were not biased by missing data, as the missing data were accounted for by an intention-to-treat procedure. In the randomized controlled trial by Lipschutz et al. [101], dropouts occurred during treatment; the reasons for dropouts during ongoing treatment were not reported and not included in the results of the study.

---------- Figure 2 ----------

In the included pilot and feasibility studies [96,97,98,99,100,102], the overall risk of bias of the reported study results must be considered as high, as there was no control or comparison group for the proof of efficacy [105].

In almost all studies, bias cannot be ruled out in the selection of study participants because, for example, only female [96] or male subjects [98] were included or selective recruitment in school classes was used [97] or subjects were selected based on the progress of exposure treatment [102]. Allocation to the respective intervention in the study took place after inclusion, with the included patients receiving the same treatment in all pilot studies [95,98,99,100]. In one study the intervention measure was adapted to the needs of the patients and extended during treatment, so that some patients received a longer intervention than others [97,102]; a bias in the intervention can be assumed here. Outcome measurement in the feasibility studies [96,97,98,100,102] was based on predefined criteria. In some studies, only part of the data was included in the results, so that selective results

were reported without the inclusion of dropouts [97,98,99,100]. One pilot study [99] did not include relevant information to assess bias in the different domains.
No assessment of the risk of bias can be made for the current study [105], as it is only a pre-registration and no study design paper was available yet.

Discussion

Principal Results

The primary aim of the review was to compile the previous studies on sensor-based psychotherapy with children and adolescents and to obtain an overview of the current state of research on the age range of the investigated patients, the mental disorders treated, the therapy methods and interventions used as well as the effectiveness of the therapy approach.

An important finding was that only a total of 10 studies met the inclusion criteria and that even in the "grey literature" only one psychotherapy study with adolescents was conducted in which a type of sensor was integrated into the therapy process. Due to the (very) limited number of studies, it can be assumed that research in this area is still in its infancy. The number of empirical studies on sensor-supported psychotherapy with adult patients is also rather low. The review by Drissi et al. [106] on sensory treatment options in psychiatric care also comprised only 12 studies. The number of empirical studies with adult patients also shows that the research field of sensory therapy in psychotherapy is still young. Due to the limited number of studies, it can be assumed that research on this topic is in early stages, both for children and adolescents and for adults.

Our narrative synthesis revealed that sensors are mainly used in psychotherapy studies in the form of ECG and EDA sensors as well as eye-tracking glasses. Sensors were especially used in behavioral therapy interventions such as exposure exercises in disorders, e.g., anorexia nervosa, PTSD, anxiety and obsessive-compulsive disorders. Studies with a depth-psychological-analytical therapy focus are lacking. It is encouraging that sensors can be used in therapy with adolescents for different goals and with different mental disorders, which illustrates the broad spectrum of possible applications of sensors. From the objectification of subjective stress perception in children [102], the measurement of speech alternation [98], movement synchrony in therapy sessions [100], heart rate during virtual exposure [97], eye movement and fixation duration during body-related exposure [96], the development of a multimodal sensor system for stress detection [99], the training of emotion recognition [104] through the investigation of gender-specific RSA differences [101] or the effects of animal-assisted therapy in comparison to normal CBT [103], sensors convey relevant information and make processes visible. The age range of the adolescents was between 6 and 19 years, with the average age of the studies indicating use by adolescents aged 12.79 years and older. This could be because adolescents aged 12 and above need less support from their parents than children aged below and can use the technical devices more independently.

The effectiveness of sensor-based psychotherapy could not be sufficiently investigated due to the small number of studies. In all 3 RCTs [101,103,104], the sensors were used with different objectives and produced interesting new results that need to be investigated further in the future. In none of the RCTs [101,103,104] did the use of sensor technology in therapy lead to a significant improvement compared to the comparison group. However, in two of the RCTs, the sensor was not used to improve the treatment outcome, i.e. to reduce symptoms, but as an indicator for comparative measurement between two cohorts [101,103]. Neither Shenk et al. [103] found an improvement in RSA with animal-assisted therapy compared to standard CBT, nor Lipschutz et al. [101] found any gender-specific change in RSA in adolescent PTSD patients. Our results confirm that research into

sensory-based psychotherapy is still in its infancy, but that the approach is feasible in principle. Future research in this novel area is necessary, as the sensors make relevant contextual information visible during treatment, allowing treatment to be adapted more specifically to the patient's needs.

Future Work

Future research should investigate the challenges associated with the novel sensor-based therapy approach and how patients experience sensor-based psychotherapy. The provision of additional patient-related information via the internet has both benefits and risks that need to be considered in the future. Patient-related health data is particularly sensitive data, so great attention must be paid to data protection in sensor-based psychotherapy and the protection of patient data [109]. Through the use of sensor technology, the patient becomes a kind of "transparent patient" [110] who appears very transparent and visible. In addition, ethical and legal aspects of the use of sensor technology in psychotherapy should be critically discussed and scrutinized [111]. More qualitative research that includes the patient's perspective seems important in order to adapt the intervention based on the experience of those being treated and to clearly highlight the benefits of sensor-based psychotherapy for patients and psychotherapists. Further randomized clinical trials with follow-up are needed to confirm the effectiveness of the sensor-based therapy approach. Once the evidence of efficacy is available, psychotherapists should be better informed and trained about the use of sensors, their application goals and their added value in psychotherapy to ensure successful application [112].

Strengths and Limitations

To the best of our knowledge, this is the first review of sensory-based psychotherapy in children and adolescents. It provides a concise overview of the latest research on the use and effectiveness of sensors in psychotherapy. Encouragingly, the review demonstrates that sensors have successfully been used in a variety of disorders and age ranges.

One limitation of the review is the low number and heterogeneity of the included studies, as there is an abundance of sensors, objectives and outcomes. Due to the limited availability of studies on sensor-based psychotherapy in children and adolescents, only three RCTs could be included, which does not clearly demonstrate the effectiveness and benefits of sensors in psychotherapy, as all randomized controlled trials investigated a different disorder with a different sensor, and also weakens the validity of the review. A second limitation of the review could be the inclusion of only English- and German-language literature and the selected cohort. It is possible that there are other studies that have been published in a different language and that studies were conducted with adolescents or young adults with a mean age over 18 years. There is a higher number of studies for the use of sensors to measure change, such as through a pre-post design or to determine biomarkers in mental disorders than studies that actively implicate the sensor in treatment.

Conclusions

The systematic review clearly shows that to date, only a few studies have been carried out on the integration of sensory technology into psychotherapy for children and adolescents. The findings from the use of sensors in psychotherapy sessions are exciting and provide objective information through the use of sensors. The additional information can be used, for example, to adjust the level of exposure exercises to the level of habitus measured by the sensors. The better adaptation of psychotherapy to the needs of children and adolescents can promote the success of therapy and possibly prevent the chronification of symptoms at an advanced age. Further research in the field of sensor-based psychotherapy seems necessary to prove the effectiveness of the approach and the benefits of sensors in psychotherapy.

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Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

Conceptualization: A.K.A., A.C., T.J.R.; data extraction: A.K.A. and M.F.; validation: A.K.A, A.P. and L.S.; preparation of the original draft, which was critically revised by all authors. All authors read and approved the final manuscript; review/editing/supervision, A.C. and T.J.R.

Abbreviations

AB	Abstract
ABMT	Attentional Bias Modification Task
ADHD	Attention Deficit Hyperactivity Disorder
AF	All fields
AI	Artificial Intelligence
ALL	All Terms
APA	American Psychological Association
CBT	Cognitive Behavioral Therapy
DSM-V	Diagnostic and Statistical Manual of Mental Disorders
ECG	Electrocardiogram
EDA	Electrodermal Activity
EEG	Electroencephalogram
GPS	Global Positioning System
F-2-F	Face-to-Face
HR	Heart Rate
HRV	Heart Rate Variability
iCBT	Internet based Cognitive Behavioral Therapy
ICD-10	International Statistical Classification of Diseases and Related Health Problems
ITT	Intention-to-treat
Mesh	Medical Subject Headings
NRCT	Non-Randomized Controlled Trials
OCD	Obsessive Compulsive Disorder
PICO(S)	Population, Intervention, Comparison, Outcome, Study Design
PROSPERO	International Prospective Register for Systematic Reviews
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PTSD	Post Traumatic Stress Disorder
ROB 2	Cochrane Risk-Of-Bias Tool for Randomized Trials
ROBINS-I	Cochrane Risk Of Bias In Non-randomized Studies of Interventions
ROBVIS	Risk-of-Bias Visualization Tool
RCT	Randomized Controlled Trial
RSA	Respiratory Sinus Arrhythmia
TI	Title
VR	Virtual Reality

VRET Virtual Reality Exposure Therapy

Multimedia Appendix

Table 1. Literature search strategies
PRISMA-P-Checklist

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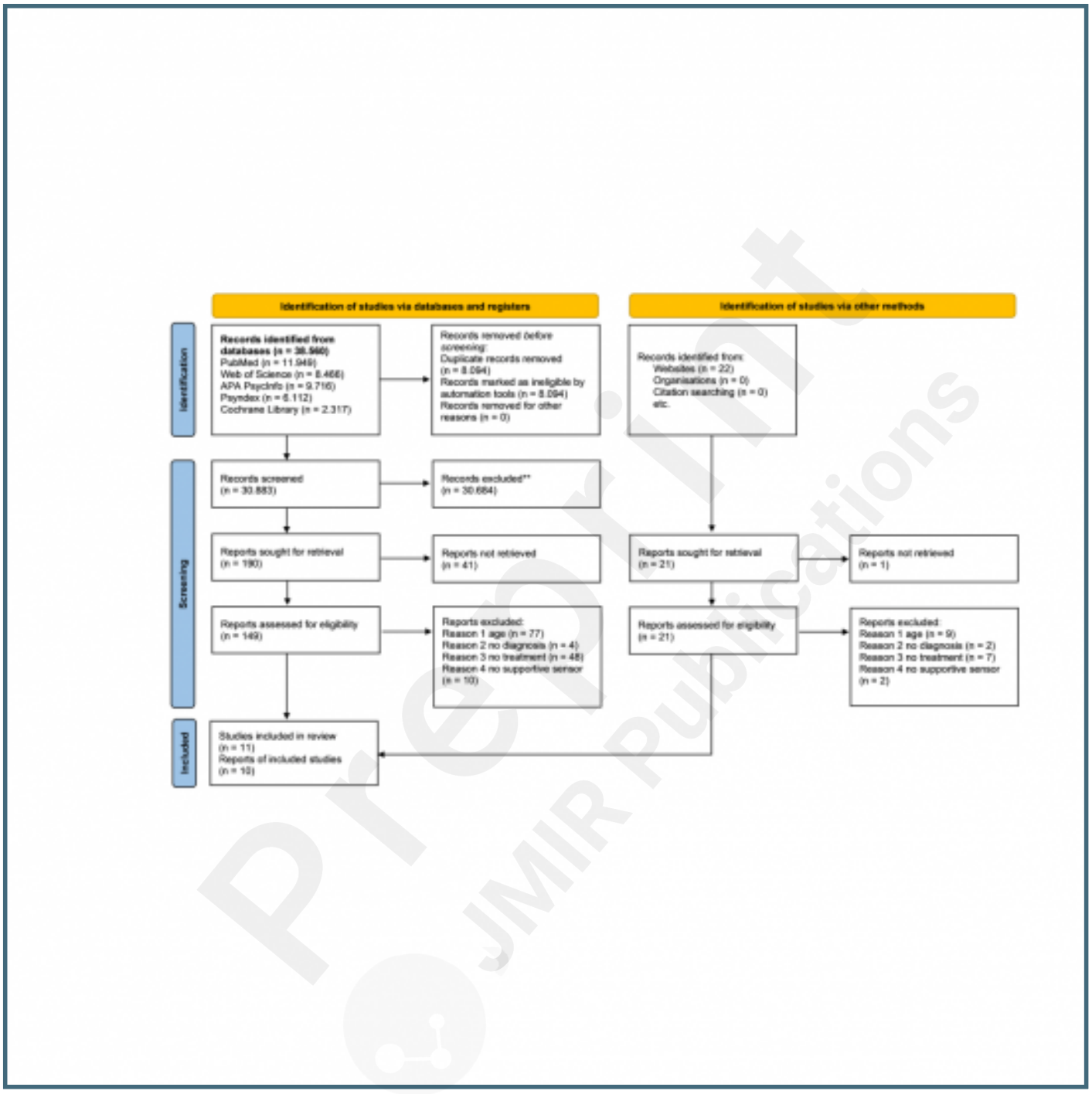
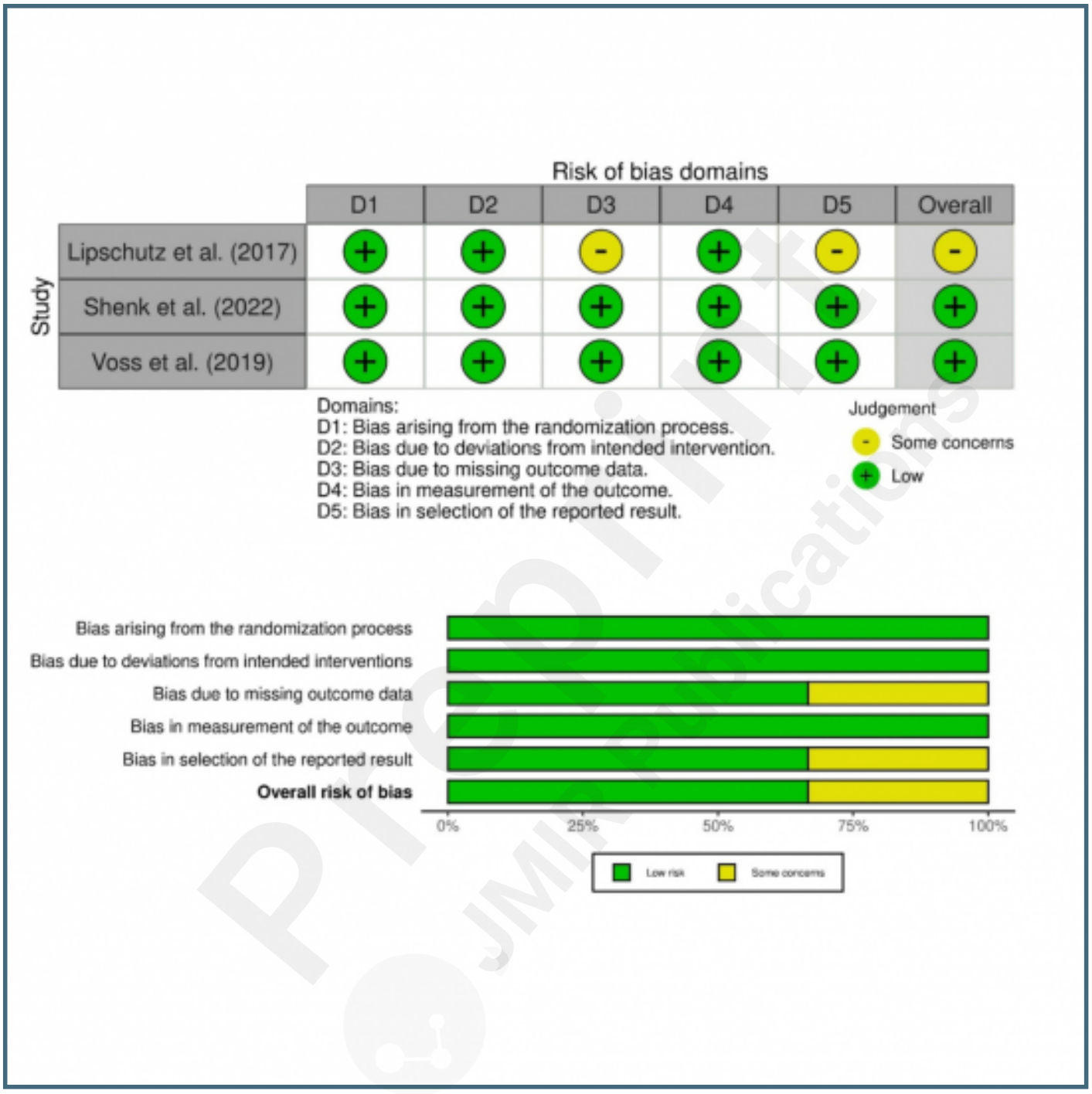
Supplementary Files

Figures

PRISMA Flow Diagram.



Cochrane Risk of Bias (ROB-2) for the risk of bias in RCTs (101,103,104).



Multimedia Appendixes

Literature search strategies.
URL: http://asset.jmir.pub/assets/7025763ffcc646b3c98cf39821d2cac2.docx

CONSORT (or other) checklists

Appendix Prisma-P Checklist.
URL: http://asset.jmir.pub/assets/dd281c57732a25f15681efa8dc0c37e2.pdf