Title: Effectiveness of the digital socio-emotional competence training Zirkus

Empathico in preschoolers: A randomized controlled trial

Abbreviated title: RCT: Effectiveness of Zirkus Empathico in preschoolers

Sandra Naumann^{1, 2} | Mareike Bayer^{1, 2} | Simone Kirst^{1, 2} | Elke van der Meer² | Isabel Dziobek^{1, 2}

¹ Berlin School of Mind and Brain, Humboldt-Universität zu Berlin, Berlin, Germany

² Department of Psychology, Institute of Life Sciences, Humboldt-Universität zu Berlin, Berlin, Germany

Correspondence to

Sandra Naumann, Berlin School of Mind and Brain, Humboldt-Universität zu Berlin, Luisenstrasse 56, 10115 Berlin, Germany

Email: sandra.naumann@hu-berlin.de

Data availability statement

Pre-registration can be found [here](#). Data and code that support the findings of this study are openly available [here](#).

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ABSTRACT

In this randomized controlled trial (RCT), the digital socio-emotional competence training Zirkus Empathico was tested in 74 Central European children (5.1(0.9) years; 34 females) within a longitudinal design (three time points: T1 = pre-training; T2 = immediately following 6-week training, T3 = 3-month follow-up). The preregistered primary outcome was empathy, secondary outcomes included emotion recognition, prosocial behavior, behavioral problem reduction; furthermore, children's neural sensitivity to facial expressions quantified with event-related potentials. Compared to controls ($N = 38$), Zirkus Empathico participants ($N = 36$) showed increases in empathy ($d = 0.28 [-0.17, 0.76]$), emotion recognition ($d = 0.57 [0.01, 1.06]$), prosocial behavior ($d = 0.51 [0.05, 0.99]$) and reduced behavioral problems ($d = 0.54 [0.08, 1.03]$). They also showed larger P3 amplitudes to happy vs. angry and neutral facial expressions post-training. Thus, Zirkus Empathico may be a promising digital training for social competence in preschoolers.

Keywords: empathy, ERPs, digital learning, preschool, prevention, socio-emotional competences

Preschool years represent an important period for the development of socio-emotional competencies (SECs). One of the most central SECs is empathy, a multidimensional construct, which comprises cognitive and affective facets as separate, but interrelated components (Dziobek et al., 2008). Cognitive empathy refers to understanding others' emotions through perspective taking (Frith & Singer, 2008). Emotional resonance may arise from cognitive comprehension and bottom-up processes related to emotion generation and understanding (Decety, 2011), which may eventually trigger feelings of empathic concern (Decety & Lamm, 2009). In turn, empathic concern is linked to prosocial behaviors (Klimecki & Singer, 2013). Empathy is thought to rely on overlapping neuronal circuits that are activated when processing own emotions (Bird & Viding, 2014; Oliver et al., 2018) and, indeed, functional awareness of own emotions represents leverage to empathic understanding (e.g., Bird et al., 2010). Similarly, recognizing others' emotions (e.g., through facial expressions) is associated positively with empathic concern (Israelashvili et al., 2020).

The mechanism subserving emotion sharing in the sense of emotional contagion is immediately present from birth, representing an instrument of social learning (Decety & Meyer, 2008). Within the first years of life, expressions of empathic concern manifest in cognitive awareness of own and others' emotional experiences (Klein et al., 2018) as well as facial and vocal expressions of prosocial actions (Davidov et al., 2013). Preschoolers rudimentary understand others' perspectives as well as reliably express and detect a variety of emotions (Denham, 2018). While positive facial expressions of others are recognized with almost adult-like precision (Durand et al., 2007), preschoolers are less accurate for negative facial expressions (Gao & Maurer, 2010). In later stages of childhood, prosocial behavior develops in relation to emotion recognition and maturing empathy (Blewitt et al., 2018). The development of functional SECs during preschool represents a critical educational task to prevent manifestations of psychiatric disorders (Fryers & Brugha, 2013), foster school

readiness (Slot et al., 2020), and subsequent academic success (Denham, 2018). However, the immense disruptions in childcare and long-term social distancing caused by the COVID-19 pandemic, significantly reduced children's everyday social learning opportunities, leading to delays in SEC development (Egan et al., 2021) and mental health deteriorations (Patrick et al., 2020).

In this context, prevention programs targeting preschoolers (e.g., Finlon et al., 2015; Koglin & Petermann, 2011) might be of great benefit to foster SEC development and to compensate for potential deficits (Wadepohl et al., 2011). Previous research indicated improvements across various SECs for programs that were implemented in educational settings such as preschool classrooms (e.g., Finlon et al., 2015; Koglin & Petermann, 2011; Wadepohl et al., 2011). However, due to a lack of time, resources, and training, SECs are rarely taught explicitly in educational settings (Adela et al., 2011). Offering SEC trainings in home settings might therefore provide a promising alternative (Lehrl et al., 2021), especially in the context of the COVID-19 pandemic, which amplified the importance of families' homes as learning environments. In addition, digital teaching and training were among the only viable options given the face-to-face restrictions during this time. To overcome past shortages in the provision of targeted SEC prevention programs and to allow socio-emotional learning within restricted contexts (e.g., within a pandemic), it might be very fruitful to implement digital training on SEC in home-based settings (Hollis et al., 2020). Digital trainings can offer relatively naturalistic social learning environments, for example, by integrating animations or video sequences of facial expressions or social interactions (Dziobek, 2012; Rosenblau et al., 2020). They may also enhance the motivation to learn new skills through persuasive design elements and gamified elements (e.g., engaging the reward system; Whyte et al., 2015).

While a steep increase in digital interventions targeting mental health in children has been noted over the last years (Hollis et al., 2017), only few studies on the impact of digital SEC trainings are available (Griffith et al., 2020). They mainly target impairments in socio-emotional skills in children with neurodevelopmental conditions such as autism (Song et al., 2019). For example, the touchscreen application “Zirkus Empathico” has been developed for children with an autism diagnosis and a developmental level between five and ten years (Kirst et al., 2015; Zoerner et al., 2016). Based on principles of autism-specific behavior therapy (e.g., prompting, reinforcement learning; Bernard-Opitz, 2009) and neurobiological models of empathy (e.g., Bird & Viding, 2014), it initially focuses on the awareness and differentiation of own emotional states and facial emotion recognition, before teaching to infer others’ emotions from emotion-eliciting contexts. Lastly, the concept of emotional resonance and appropriate prosocial actions expressing empathic concern towards others’ emotions within various contexts are conveyed.

A randomized controlled trial (RCT) testing the effectiveness of Zirkus Empathico found moderate effects on empathy and emotion recognition after six weeks of caregiver-guided intervention (Kirst et al., 2022). While improvements were not present anymore during the three-month follow-up assessment, more stable effects were reported for children’s awareness of their own emotions, emotion regulation, and prosocial behavior (Kirst et al., 2022). Due to its simplified language and age-appropriate visualized content, the Zirkus Empathico training might be equally suitable for the needs of preschoolers without formal diagnosis. Since it targets the training of SECs, which still lacks systematic implementation throughout the (pre-) schooling contexts (Wu et al., 2019), it could, if proven effective, add tremendous value as educational tool.

Therefore, within our present study, we aimed to extend the purpose of the Zirkus Empathico training and thus assess the effect of this six-week digital SEC training on

neurotypical preschoolers between 4 and 6 years. Since studies examining the preventative potential of digital trainings for preschoolers' SEC development are scarce and do not consider children's home learning environment, we aim to inform and extend the research on digital tools within this area. In order to match the study outcomes to the intervention targets of Zirkus Empathico, empathy (comprising cognitive and affective facets) was defined as the primary outcome. It was hypothesized that a six-week training with Zirkus Empathico would result in greater improvements in empathy in the training group compared to active controls engaging in a digital foreign language acquisition training. To further quantify effects of Zirkus Empathico on a broader range of outcome measures, changes in emotion recognition and prosocial behaviors were assessed as secondary outcomes.

Finally, since previous digital intervention studies have paid minimal attention to neurobiological systems in their evaluation of treatment efficacy, the study additionally examined training-induced changes in event-related potentials (ERPs), underlying the processing of facial expressions. The complementation of behavioral findings with brain measures in the context of the evaluation of treatment efficacy may allow tapping into the development, potential maladaptive processes and resilience in fuller complexity (Cicchetti & Gunnar, 2008). Indeed, as one of the first, Wu and Kim (2019) presented promising evidence in 3-5-year-old preschoolers by assessing the touchscreen application Empathy World with behavioral measures and ERPs. Post-training, the authors found significant increases in attention to others' feelings as well as higher empathic concern which was indexed by modulation of the P2 component (Wu & Kim, 2019). Based on findings that facial expression processing undergoes continuous maturation in childhood with young children using very early processing to discriminate emotions (Batty & Taylor, 2006), we decided to investigate changes in the early P1 and N170 components. Both ERPs were previously associated with initial sensory and automatic detection of facial expressions in children and adults (Ding et

al., 2017; Hinojosa et al., 2015). In addition, we analyzed the P3 component, which is sensitive to the processing of facial expressions in children (Anokhin et al., 2010; Naumann et al., 2022) and was previously associated with their motivational saliency (Hajcak et al., 2010). We hypothesized that after the training, P1 and N170 amplitudes would be larger for the Zirkus Empathico group as compared to controls, indicative of attentional resources dedicated to facial expression processing. Similarly, we expected larger P3 amplitudes for later neural processing suggesting greater emotional receptiveness within the Zirkus Empathico group when compared to controls. In additional explorative analyses, possible long-term implications were examined as well as whether parent ratings and child SEC assessments were positively related to ERP amplitudes in response to facial expressions.

Method

Participants

The study protocol was pre-registered at the German register for clinical studies ([DRKS-ID: DRKS00015789](#)) and approved by the local ethics committee. We recruited families by website postings, newspapers, and postal acquisition. They were compensated with €24 for study participation. The trial lasted from October 2018 to July 2020. Due to the COVID-19 pandemic, it was interrupted from March to Mai 2020.

Sample size calculation within the pre-registration was based on a previous meta-analysis reporting a small effect size $d = 0.47$ [0.08, 0.86] (Grynszpan et al., 2014) when examining the effect of technology-based training in children on the autism spectrum (which represented the best estimate at time of pre-registration). Assuming a 20% attrition rate (e.g., Wadepohl et al., 2011), we included a total sample of 74 intention-to-treat (ITT) participants to provide 80 % power at a two-sided 5% α -level (G*Power; Faul et al., 2007). We excluded participants with (a) a nonverbal IQ below 70 (Coloured Progressive Matrices, CPM; Raven, 2002), (b) verbal age under 4 years (Peabody Picture Vocabulary Test, PPVT; Dunn & Dunn,

2007), (c) autism symptomatology (Social Responsiveness Scale, SRS; Constantino & Gruber, 2005, cut-off > 76), (d) neurological or psychological disorders, (e) training- or EEG-impairing medication (e.g., stimulants), as well as (f) parallel participation in other socio-emotional trainings or clinical trials. Fig. 1 provides an overview of participants' flow through each stage of the RCT.

Figure 1. Flow Diagram of the trial. ITT = intention-to-treat, PP = per protocol, CC = complete cases.

All participants for the training group (N = 36) and control group (N = 38) were of Central European origin. To describe families' socioeconomic status (SES), we summarized family income, caregiver occupation, and education with the Winkler index (Winkler & Stolzenberg, 1998). Families' SES ranged from medium to high. There were no differences

between groups in terms of their participant characteristics. Table 1 provides screening and demographic information.

Table 1. Baseline participant sociodemographic information.

Baseline characteristics		Controls (N= 38)	Zirkus Empathico (N= 36)
Sex	Female / Male	18 / 20	16 / 20
Age	Years <i>M (SD)</i>	5.1 (0.9)	5.1 (0.8)
SES (Winkler Index)	Low <i>n (%)</i>	3	3
	Medium <i>n (%)</i>	24	20
	High <i>n (%)</i>	73	77
Siblings	No siblings <i>n (%)</i>	11	19
	Up to two siblings <i>n (%)</i>	87	69
	More than two <i>n (%)</i>	2	12
Verbal age	PPVT percentiles <i>M (SD)</i>	68.5 (24.8)	68.4 (25.0)
Nonverbal IQ	CPM score <i>M (SD)</i>	14.8 (3.7)	13.9 (3.4)

SES = socioeconomic status (Winkler Index; Winkler & Stolzenberg, 1998), PPVT = Peabody Picture Vocabulary Test, CPM = Coloured Progressive Matrices.

Procedure

Baseline SECs were examined with child assessments and parent ratings prior to training assignment at the study center. Eligible participants were randomly allocated to the Zirkus Empathico or control group accounting with covariate-adaptive allocation accounting for the covariates age (below vs. above 5.3 years) and gender (male vs. female, carried out with QMinim; Saghaei & Saghaei, 2011; probability method: biased coin minimization; base probability: 0.8). Due to the nature of the training, families could not be blinded to allocation status. However, study advertisement indicated to provide both early language and socio-emotional competence trainings. Consequently, the focus of the study was revealed to the families only after they had completed the study. Parents of both groups gave informed consent, received on-site instructions and a training manual. They were asked to only assist their child during the training in case of questions or technical problems. Each family received a tablet-PC with the assigned touchscreen application to practice at home. Training lasted six weeks, with a weekly engagement of minimum 60 minutes. The *Screen Time* tracking application (Screen Time Labs) was used to monitor training engagement and to

limit daily training time to 30 minutes. After six weeks of training at home, parent ratings and child assessments were repeated at the study center by an evaluator who was blind to group assignment. Furthermore, children participated in an EEG task. In addition to the pre-registered procedure, we explored possible long-term implications of the Zirkus Empathico training by re-assessing children's SECs with online parent reports three months after training completion.

Intervention

As shown in Figure 2, Zirkus Empathico targets awareness and differentiation of own and others' emotions, empathy, and prosocial behaviors through interactions with naturalistic video sequences of facial expressions and social situations (Kirst et al., 2015; Kirst et al., 2022). The child can practice with different modules: In the first module, the child specifies inner emotional states associated with a specific context by using a virtual emotion manikin. The manikin constitutes a central element of the training to support the child in expressing perceived emotions on a two-dimensional scale indicating arousal and valence levels. Within the second module, the child is asked to identify emotion labels for facial expressions of adult and child protagonists (emotions: happy, sad, angry, anxious, and surprised). The third module offers possibilities to understand emotion eliciting contexts. Emotion-inducing video clips visualize the emotion-eliciting context of another person; the child's task is to identify the emotional state of this person. Within the last module, the child is presented with a third person's emotional expression embedded in an emotion-triggering context. Afterward, the child can decide how to react to the other person (e.g., go and talk to this person), fostering empathy and prosocial actions (See Description S1 for further details).

As control training, we employed the touchscreen application Squirell & Bär (the Good Evil GmbH), which fosters early foreign language acquisition through the interaction with basic English words and phrases (Note: Our sample included native German speakers

without prior knowledge of English). We chose this application as control training because of its comparability in terms of training length, intensity, cognitive demands as well as parental involvement.

Figure 2. Training elements of Zirkus Empathico. Left: Overview of different training modules targeting own and others' emotion recognition from situational cues; empathy and prosocial actions. Middle: Exemplary module sequence of identifying other people's facial expressions. Right: Interactive manikin to visualize own and other's emotional states with sliders for valence and arousal for a naturalistic video sequence (Kirst et al., 2015).

Measures

Primary outcome: Empathy. Pre- and post-training, parents filled out the 23-item *Griffith Empathy Measure* (GEM; Dadds et al., 2008). The internal consistency in our sample at baseline and T2 (immediately following 6-week training) was sufficient (T1: Cronbach's $\alpha = .64$; T2: Cronbach's $\alpha = .72$). Previous literature likewise indicated good convergence with child ratings and sufficient reliability (Cronbach's $\alpha = .81$; Dadds et al., 2008). To complement GEM findings, we used parent ratings and child assessments of the *Inventory to survey of emotional competences for three- to six-year-olds* (EMK 3-6; Petermann & Gust, 2016). The child assessment includes tasks on perspective taking and emotion sharing. Children had to take a doll's perspective in different situations (e.g., the doll is afraid of dogs, what happens if the doll meets a dog?). They had to express and justify actions to help the doll (e.g., to chase the dog away if the doll is afraid of dogs). According to Gust et al. (2017), EMK 3-6's internal consistency (Cronbach's $\alpha = .78-.90$) and construct and criterion validity have been found to be sufficient. These observations match our internal consistency findings

(parent ratings T1: Cronbach's $\alpha = .81$, T2: Cronbach's $\alpha = .96$; child assessment: T1: Cronbach's $\alpha = .86$, T2: Cronbach's $\alpha = .84$).

Secondary outcome: Emotion recognition. We used the child assessment and parent rating of the EMK 3-6 to examine emotion recognition abilities. Children had to recognize other children's emotions on picture cards and name the mimic markers of these emotions (e.g., raised eyebrows for surprised faces).

Secondary outcome: Prosocial behavior. Prosocial behavior was examined with the EMK 3-6 child assessment (see EMK 3-6 empathy assessment description) and the 25-item parental report subscales prosocial behavior and reduction of problematic behaviors of the *Strengths and Difficulties Questionnaire* (SDQ; Goodman, 1997). SDQ's concurrent and divergent validity and internal consistency was confirmed in a study with teacher and parent ratings of preschoolers (Cronbach's $\alpha = .77$; Mieloo et al., 2012). We also detected sufficient internal consistency at baseline (Cronbach's $\alpha = .77$) as well as T2 (Cronbach's $\alpha = .92$).

Secondary outcome: Neural sensitivity to facial expressions. We recorded EEG, while participants observed faces of happy, angry, and neutral expressions (See DescriptionS2). The task was administered using the software Presentation® (Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com). For each trial, a fixation cross was on screen for 500 ms, followed by a blank screen with a jittered inter-stimulus-interval (400-600 ms), a face stimulus (1,000 ms) and a blank screen as inter-trial-interval (1,000 ms). We presented three blocks with 60 trials each (180 trials total). Within blocks, no condition, gender or valence was repeated more than three times successively. 13% of the trials displayed ape faces instead of human faces. Participants were asked to press a button when they saw an ape face (overall accuracy: $M = 72.30\%$ (27.97)). Ape face trials were used to ensure children's

attention and were not analyzed further. Ten practice trials that included ape and human faces preceded the test session.

Additional analyses: Training time, fidelity and satisfaction. We used Screen Time to measure children's training time. Additionally, parents recorded the training time in a paper-based diary. Since Screen Time tracking data was not provided or accurate enough for 27 % of the sample (e.g., due to technical issues), we used parent ratings as training time estimations (Correlation between parent ratings and tracking times ($r(49) = .46, p < .001$). Post-training, parents evaluated parent engagement, children's level of acceptance and satisfaction as well as implementation into daily life by rating several items on a five-point rating scale and by answering open-ended questions (See TableS1).

EEG recording, processing, and analysis

We recorded continuous EEG data with in-house QRefa Acquisition Software (Version 1.0 beta; MPI-CBS, Leipzig, Germany) using a Refa amplifier system (Twente Medical System International B.V). EEG signal was collected from 46 Ag/AgCl electrodes, according to standard positions (International 10-20 system of electrode placement; See FigS1) held on an elastic cap (EasyCap GmbH, Germany). EEG data were sampled at 500 Hz and online-referenced to CZ (ground electrode at Fp1). Electrode impedances were kept below 10 k Ω ; electro-oculograms were registered with electrodes at the outer canthi of both eyes and at the orbital ridge of the right eye. We carried out further offline pre-processing in MATLAB (Version: 2016b) using EEGLab (Delorme & Makeig, 2004) and ERPLab (Lopez-Calderon & Luck, 2014). Data was high-pass filtered at 0.01 Hz, low-pass filtered at 30 Hz (IIR Butterworth 2nd order filter) and notch-filtered at 50 Hz (Parks-McClellan Notch filter). Subsequently, EEG data was re-referenced to the average of all data channels (excluding eye channels). We removed ocular artifacts based on an independent component analysis (ICA, EEGLAB: runica algorithm) results. Afterwards, data were segmented from 200 ms before

stimulus onset to 1,000 ms post-stimulus onset and baseline-corrected using the mean activity during the 200 ms prior to stimulus onset. Segments that still contained artifacts were removed based on a semi-automated artifact rejection of voltage (exceeding $\pm 200 \mu\text{V}$) and visual inspection of each trial. No differences between number of trials per facial expression were detected ($F(2, 177) = 0.01, p = .99$; happy: $M = 49.02 (10.12)$; angry: $M = 49.23 (10.27)$ and neutral: $M = 49.08 (9.58)$).

Regions of interest were selected based on previous research (Batty & Taylor, 2006) and confirmed by visual inspection of averaged ERP topographies across all conditions. P1 and P3 were quantified at electrodes PO3, PO7, PO9, O1, O2, Oz, PO4, PO8, PO10, and the N170 at electrodes P7, TP7, CP5 and P8, TP8, CP6. P1 peaks were determined in the time window of 90 to 130 ms; N170 peaks from 180 to 220 ms after stimulus onset. Individual P1 and N170 peaks were identified using peak detection procedures and quantified as mean amplitude in the time window of 20 ms surrounding the individual peak. The P3 was quantified as mean activity between 300 to 500 ms after stimulus onset.

Data analysis

Statistical analyses were performed using R-Studio (R Core Team 2019 version 4.0.2) and reported according to CONSORT guidelines (Schulz et al., 2010). Hypotheses and methods were specified within the pre-registration. Our analysis plan was adapted from pre-existing intervention studies (e.g., Siebelink et al., 2022). In addition, we also carried out complementary analysis to explore possible long-term effects and associations between behavior and brain variables. Study-related data and code can be found in a [open-access repository](#).

Confirmatory analysis

To investigate both the effect of the assigned and actually received intervention, the analyses of primary and secondary outcomes were based on ITT and per-protocol (PP)

samples (See Figure 1). Missing data ($N = 1$) were imputed by multiple imputation with chained equations (MICE; mice R package version 3.13.0) employing predictive mean matching (Morris et al., 2014; number of imputation sets $m = 50$). All primary and secondary endpoints as well as group, age, and sex were integrated as predictors in the imputation model.

For primary and secondary outcomes, we calculated change scores as the difference between participants' pre-training (T1) and post-training (T2; immediately following the 6-week training) parent rating and child assessment scores. Subsequently, we carried out separate analyses of covariance (ANCOVAs) for each primary and secondary outcome with change score as dependent variable and training as between factor, covarying for participant's pre-training scores. We report Cohen's d as effect size (small effect = 0.2; medium effect = 0.5, large effect = 0.8; Cohen, 1988). Results of primary and secondary outcomes did not change when controlling for training time (See "<https://naumsand.github.io/zerp/>" under "Confirmatory Analysis").

For the analysis of the P1, N170, and P3 at T2, we excluded participants without an EEG measurement at post-training ($N = 3$) or too few ERP trials (below 10 trials, Bruce et al., 2020; $N = 4$). We computed separate analyses of variance (ANOVAs) on participants with sufficient EEG data quality (Zirkus Empathico $N = 33$; Controls $N = 34$) with ERP amplitude as dependent variable, training as between factor, and facial expressions (happy vs. angry vs. neutral) as within factor.

Complementary analysis

As complementary analysis, we examined training fidelity differences between groups with Welch's t -tests (tadaatoolbox R package version 0.17.0). Exploratory long-term analyses were conducted with a complete case (CC) sample including families who completed T1, T2 as well as T3 (three-month follow-up) parent ratings (Zirkus Empathico $N = 17$; Controls $N =$

24). This procedure was chosen because with a data loss of 44.6 %, imputation would have been likely to be biased (Armijo-Olivo et al., 2009). We computed change scores as the difference between participants' pre- and post-training parent rating scores (T1-T2 and T1-T3). Subsequently, we calculated separate ANCOVAs for each primary and secondary parent outcome with change score as dependent variable, training as between factor and time as within factor (T1-T2 vs. T1-T3), covarying for participant's pre-training scores. Lastly, we performed exploratory correlational analyses using Pearson's correlations across with the sample of the ERP analysis to associate brain and T2 behavior variables which yielded training-induced changes.

Results

Confirmatory analyses: Primary outcome

As shown in Figure 3, we did not detect group differences for empathy measured by the GEM parent rating (GEM_p ITT: $d = 0.23$, 95% CI [-0.23, 0.70], $p = .32$; PP: $d = 0.20$ [-0.26, 0.68], $p = .35$). In contrast, EMK 3-6 parent ratings indicated larger increases in empathy for the Zirkus Empathico group compared to controls (EMK EM_p ITT: $d = 0.28$ [-0.17, 0.76], $p = .045$; PP: $d = 0.32$ [-0.15, 0.80], $p = .02$). However, no difference was found for EMK child assessments (EMK EM_{CH} ITT: $d = 0.29$ [-0.016, 0.77], $p = .07$; PP: $d = 0.28$ [-0.19, 0.76], $p = .09$).

Confirmatory analysis: Secondary outcomes

Emotion recognition. As shown in Table 2, child EMK 3-6 assessments yielded significantly larger increases for emotion recognition in the Zirkus Empathico group compared to controls (EMK ER_{CH}: ITT: $d = 0.57$ [0.01, 1.06], $p = .006$; PP: $d = 0.54$ [0.08,

1.04], $p = .01$), whereas parent ratings did not reveal significant results (EMK ER_P ITT: $d = 0.04 [-0.42, 0.50]$, $p = .15$; PP: $d = 0.05 [-0.42, 0.52]$, $p = .05$).

Figure 3. Parent and child ratings of socio-emotional competence (SEC) reports. Orange: Zirkus Empathico group. Grey: Control training. Error bars indicate standard errors (SE); d z-standardized represents the standardized change scores (difference between post- and pre-training values). Note: Standardization was achieved by subtracting each value from the variables mean and dividing them by the variable's standard deviation $(x - \bar{x}) / SD$. Standardization was only carried out for visualization purposes; statistical analyses were carried out with the raw d values. GEM = Griffith Empathy Measure; EMK = Inventory to survey of emotional competences for three- to six-year-olds; EM = Empathy; ER = Emotion recognition; SDQ = Strength and Difficulties Questionnaire; PB = Prosocial behavior; BP = Behavioral problems. P = parent rating; CH = child assessment.

Prosocial behavior. The EMK 3-6 child assessment for prosocial behavior did not display group differences (EMK PB_{CH} ITT: $d = 0.02 [-0.44, 0.48]$, $p = .57$; PP: $d = 0.04 [-0.43, 0.51]$, $p = .54$). SDQ parent ratings, however, showed larger increases in prosocial behavior (SDQ PB_P ITT: $d = 0.51 [0.05, 0.99]$, $p = .008$; PP: $d = 0.46 [-0.01, 0.95]$, $p = .004$) and greater declines in problem behavior for the Zirkus Empathico group compared to controls (SDQ BP_P ITT: $d = 0.54 [0.08, 1.03]$, $p = .01$; PP: $d = 0.62 [0.16, 1.12]$, $p = .01$).

Table 2. Outcome measures at baseline (T1) and after training (T2).

Parental rating	Controls (N = 38)			Zirkus Empathico (N = 36)			<i>F</i> value	<i>p</i>	Cohen's <i>d</i> [95% CI]
	T1	T2	D (T2-T1)	T1	T2	D (T2-T1)			
Empathy (GEM _P)	15.95 (14.90)	14.11 (18.07)	-1.84 (13.45)	15.47 (13.19)	16.92 (15.21)	1.44 (14.76)	0.99	.32	0.23 [-0.23, 0.70]
Empathy (EMK EM _P)	17.76 (3.17)	17.71 (3.35)	-0.05 (2.82)	19.00 (3.55)	19.75 (3.36)	0.75 (2.80)	4.14	.045	0.28 [-0.17, 0.76]
Emotion recognition (EMK ER _P)	10.29 (1.64)	10.50 (1.33)	0.21 (1.21)	10.89 (1.37)	11.14 (1.07)	0.25 (0.84)	2.13	.14	0.04 [-0.42, 0.50]
Prosocial behavior (SDQ PB _P)	5.37 (1.50)	7.32 (1.74)	1.95 (2.08)	5.31 (1.62)	8.25 (1.34)	2.94 (1.55)	7.50	.008	0.51 [0.05, 0.99]
Problem behavior (SDQ BP _P)	15.89 (3.14)	9.24 (3.76)	6.66 (3.22)	15.75 (3.75)	7.22 (3.28)	8.53 (4.02)	7.01	.009	0.54 [0.08, 1.03]
Child assessment									
Empathy (EMK EM _{CH})	10.53 (3.51)	11.32 (3.79)	0.79 (3.45)	11.32 (3.06)	13.11 (3.30)	1.78 (3.21)	3.50	.07	0.29 [-0.02, 0.77]
Emotion recognition (EMK ER _{CH})	16.00 (5.05)	17.42 (4.75)	1.42 (2.78)	16.19 (4.18)	19.86 (4.42)	3.67 (4.78)	7.98	.006	0.57 [0.01, 1.06]
Prosocial behavior (EMK PB _{CH})	11.82 (3.44)	13.39 (2.96)	1.58 (2.73)	12.28 (2.17)	13.92 (2.42)	1.64 (3.20)	0.33	.57	0.02 [-0.44, 0.48]

Baseline (T1) and post-training (T2) data are means (SD) from ITT analyses. D = difference score between T2 and T1 (except for problem behavior where T1-T2 was calculated as the score is inverted). *F* and *p* values refer to the training main effect from the ANCOVAs without training time. GEM = Griffith Empathy Measure; EMK = Inventory to survey of emotional competences for three- to six-year-olds; EM = Empathy; ER = Emotion recognition; SDQ = Strength and Difficulties Questionnaire; PB = Prosocial behavior; BP = Behavioral problems. P = parent rating; CH = child assessment.

ERP measures. ERP trajectories and associated topographies are displayed in Figure

4. For the P1, no training effect ($d = 0.19$ [$<0.01, 0.60$], $p = .43$), but a main effect of facial expression was found ($d = 0.16$ [$<0.01, 0.37$], $p = .01$). P1 amplitudes were larger for happy vs. neutral faces ($p = .008$). We detected no amplitude differences for angry vs. neutral faces ($p = .11$), or for happy vs. angry faces ($p = .56$). The interaction of training and emotion did not yield significant results ($d = 0.08$ [$<0.01, 0.20$], $p = .30$). N170 amplitudes were neither modulated by training ($d = 0.08$ [$<0.01, 0.12$], $p = .73$), facial expression ($d = 0.07$ [$<0.01, 0.10$], $p = .66$), nor their interaction ($d = 0.07$ [$<0.01, 0.18$], $p = .63$; due to a lack of N170 hemispheric differences averaged ROI results are reported).

Concerning the P3, we did not detect a main effect of training ($d = 0.03$ [$<0.01, 0.05$], $p = .89$), but a significant effect of facial expression ($d = 0.12$ [$<0.01, 0.31$], $p = .03$). P3 amplitudes were larger for happy vs. neutral faces ($p = .02$), while P3 amplitude differences for angry vs. neutral faces ($p = .29$) or happy vs. angry faces were not statistically significant ($p = .29$). The facial expression main effect was qualified by an interaction with training ($d = 0.11$ [$<0.01, 0.30$], $p = .04$). The Zirkus Empathico group showed larger P3 amplitudes for happy vs. neutral faces ($p = .01$) and happy vs. angry faces ($p = .02$). None of the other post-hoc tests yielded significant results (all $p > .16$).

Figure 4. ERP trajectories and morphologies separated for (left) controls and (right) Zirkus Empathico group. Averaged P1, N170 and P3 waveforms for happy (green), angry (blue) and neutral (grey) facial expressions (ROI P1/P3 electrodes: PO3, PO7, PO9, O1, O2, Oz, PO4, PO8, PO10; ROI N170 electrodes: P7, TP7, CP5 and P8, TP8, CP6). Shaded areas indicate the time windows used to identify participants' individual peaks and mean amplitudes. Topographies summaries the averaged P3 activity (300-500 ms) displaying amplitude difference scores for facial expression contrasts (from the left): Controls happy–neutral, angry–neutral and happy–angry; Zirkus Empathico group happy–neutral, angry–neutral and happy–angry.

Complementary analysis

Training fidelity. Both groups showed high levels of training motivation with similar training engagement across groups (total time used in minutes: Controls $M = 323.76$

(127.95), Zirkus Empathico $M = 351.21$ (122.52); $t(69) = -0.92$, $p = .36$). Parental engagement did not differ between groups (rating from 1-5: Controls $M = 3.38$ (1.20), Zirkus Empathico $M = 3.11$ (1.40); $t(70) = 0.85$, $p = .40$). Parents also indicated that the training was compatible with daily routines (See TableS1).

Exploration of long-term effects. For the GEM parent rating, we detected a group effect ($d = 0.77$ [0.21, 1.31], $p = .002$) with larger increases in empathy for the Zirkus Empathico group compared to controls from T1 to T3. None of the other outcomes indicated long-term SEC changes (See TableS2).

SEC measure associations with P3 amplitudes. We correlated post-training (T2) values of SEC measures, which indicated training-induced changes (EMK EM_P, EMK ER_{CH}, SDQ PB_P, SDQ BP_P) with P3 amplitude difference scores, which were sensitive to training group differences (happy minus neutral; happy minus angry). We did not detect any significant correlations (all $p > .11$; see TableS3).

Discussion

Digital technology offers new ways of transforming preventative and therapeutic spaces to bridge the mental health gap for children, particularly in times of the COVID-19 pandemic when children lack face-to-face social interactions and learning opportunities. In the current study, we evaluated the effectiveness of the digital SEC training Zirkus Empathico over the course of six weeks in preschool children. The training group, as compared to the active control group, showed gains in parent empathy ratings, child assessment scores of emotion recognition, parent ratings of prosocial behavior, and reduced problem behavior directly after the training. As further secondary outcome, we complemented the behavioral measures with neural markers examining training-induced emotion processing changes in sensory (P1, N170) and higher-order (P3) ERPs. Training-

induced changes were visible for higher-order processing stages associated with emotion sensitivity: The Zirkus Empathico group showed larger P3 amplitudes for happy vs. neutral and angry faces. Exploratory analyses of a three-month follow-up indicated gradual increases in parent empathy ratings for the Zirkus Empathico group over time.

In line with our hypothesis, the Zirkus Empathico group, compared to controls, showed improvements in the primary outcome measure empathy, reflected by greater increases in the EMK 3-6 empathy parent rating. This finding resonates with previous research reporting improvements in empathy after preschoolers engaged with a digital SEC training in the classroom setting (Wu & Kim, 2019). Interestingly, no training group differences were detected for the GEM empathy parent rating as further primary outcome. The reason for this discrepancy might lie in the fact that the EMK 3-6, in contrast to the GEM, includes items for prosocial behavior associated with empathic processing (e.g., comfort someone when he or she is sad). This might indicate that Zirkus Empathico fostered preschoolers empathy specifically in children's direct actions toward others.

In concordance, we detected increases in our secondary outcomes prosocial behavior and emotion recognition, and reductions of behavioral problems after the training for the Zirkus Empathico group, which is in line with previous studies using classroom SEC trainings (Wadepohl et al., 2011). The delivery of the training content (e.g., naturalistic videos of facial expressions) may have triggered an authentic perception of social cues (Kliemann et al., 2013; Wu et al., 2020). Additionally, as suggested by parent fidelity ratings, children were highly motivated to engage in the Zirkus Empathico training and families needed minimal effort to implement the training into their everyday lives'.

As further secondary outcome, we examined facial expression processing with early and late ERPs. Contrary to our hypothesis, our results did not suggest that the Zirkus Empathico training affected early stages of facial expression processing. Further, at later

processing stages, the result pattern did not match our hypothesis: P3 amplitudes were larger for happy vs. angry and neutral facial expressions in the Zirkus Empathico group, but controls did not show significant P3 amplitude modulations by facial expressions nor differences to the Zirkus Empathico group. One possible post-hoc explanation for the larger P3 amplitudes for happy faces could be that the Zirkus Empathico group allocated more processing resources toward positive emotional stimuli. Previous research linked the P3 to emotion regulation processes (Hajcak et al., 2010), suggesting that Zirkus Empathico might lead to reorientation processes towards positive emotional states, which has been identified as effective regulation strategy (Tugade & Fredrickson, 2007). Allocating more attention to positive images may also serve as a protective factor to avoid maladaptive affective responses (Lagattuta & Kramer, 2017). This neural pattern parallels reported improvements of the Zirkus Empathico group for empathy and prosocial behavior as well as previous research on this digital training reporting emotion regulation improvements (Kirst et al., 2022).

Within our first exploration of possible long-term effects, we found that children's capacity of empathy, i.e., their understanding of others' feelings seem to have increased over time, with stronger effects arising months after the training ended ("sleeping effect"; Blewitt et al., 2018), while improvements in emotion recognition and prosocial behaviors were not maintained in the long run. For the latter SECs, the training intensity may have been too low for long-term, sustainable transfer into daily family interactions. Given the exploratory nature of the long-term analyses, this data should be interpreted as tentative. Further, the chosen complete cases analysis favors a subset of the study's participants which may also hamper generalizability of the findings.

Further research is needed to investigate how sustainable transfer from digital SEC trainings can be accomplished. While our home-based training spanned only six weeks, typical classroom-based SEC trainings which have proven effective were realized over

several months up to a year (Wadepohl et al., 2011). Thus, future studies should examine the effectiveness of long-term digital SEC trainings. In addition, the children of our study practiced with minimal parental guidance. However, as indicated by a previous Zirkus Empathico training study, parental involvement might enhance transfer into daily life with parents serving as a role model (Kirst et al., 2022). Thus, further research could compare the transfer effects of the Zirkus Empathico training varying the amount of parental involvement. As suggested by the ERP findings, further research would also profit from an in-depth understanding of how emotion regulation plays into the mechanisms of the training by e.g., an integration of an emotion regulation based EEG paradigm.

Taken together, Zirkus Empathico seems to be effective in enhancing brain and behavioral measures associated with SECs in preschoolers, indicating the preventative potential of this digital training. Thus, as being easily accessible by the public with low costs, digital SEC trainings could be implemented more widely as prevention strategies to reduce the risk for mental illness among children and adolescents. Zirkus Empathico has also been shown effective in a clinical sample of children on the autism spectrum (Kirst et al., 2022). Digital tools as a support to alleviate mental disorders have gained momentum in past years, given the wide accessibility and the potential to ease pressures on face-to-face health care services (Halldorsson et al., 2021). This is of special importance given that traditional trainings cannot be maintained when social contacts are severely reduced due to external circumstances, as has been the case in the COVID-19 pandemic (Patrick et al., 2020). Further, digital trainings might not only reach populations in health care-deprived areas but also populations which might otherwise not be wanting to seek help, e.g. to avoid stigma associated with visits to mental health services (Halldorsson et al., 2021). In addition, traditional classroom trainings may require trained professionals, whereas digital solutions are more flexible in terms of pace and timing of the training without necessarily needing an

in-person instructor. Since children can repeat exercises as often as they want, digital trainings also offer the advantage of being more targeted toward their individual learning speed as compared to traditional classroom trainings.

As indicated by this study and previous research on Zirkus Empathico (Kirst et al., 2022) some remarks are necessary regarding the implementation of digital trainings: Young children increasingly engage with digital technology (Hollis et al., 2017) and delivering trainings online might contribute to their daily screen time. Thus, parental guidance and access restrictions provided by the training (Reid Chassiakos et al., 2016) should be in place to monitor and control for excessive use. In addition, our training targets children's SECs, which most importantly needs to be transferred into the child's daily interactions. Thus, the SEC training should provide options to facilitate family participation to further help modelling effective social and learning interactions outside the digital training environment (Kirst et al., 2022; Reid Chassiakos et al., 2016).

The findings of this study have to be seen in light of some limitations. Firstly, one has to note that our training effects are partly based on parental evaluations likely prone to rater biases. In our study, however, parents only knew that their child would either train their language or social skills; the purpose of the app their children were actually practicing with was revealed only after the end of participation to reduce potential biases. Further, we were not able to map the exact neural trajectory before and after training because we acquired EEG measurements exclusively post-training. Additionally, we used an implicit EEG task to assess facial expression processing, which only provides limited insights on how well children recognized the different facial expressions. Given that we evaluated the training in a sample of middle to upper class families, this restricted SES range might also reduce our findings' generalizability. Lastly, our first attempts to correlate report and brain data did not yield any significant results, potentially due to a lack of power. Hence, future research may include a

larger sample to reveal potential effects.

Conclusion

Our study highlights the potential of digital SEC trainings as preventative tools for young children's socio-emotional development. After six weeks of training at home, preschoolers showed improvements in empathy, emotion recognition, and prosocial behavior. Additionally, we detected disparate brain patterns between controls and the training group potentially indicating processing differences for happy facial expressions and thus providing first evidence of changes in neural plasticity through the SEC training. Further research is warranted to examine long-term transfer of these skills as well as the exact neural mechanisms behind the training-induced changes.

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