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The Influence of a Socially Assistive Robot on Mood, Anxiety, and Arousal in Children

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Socially assistive robots (SARs) represent a promising resource for efforts to improve children's mental health and alleviate suffering on a large scale. However, the effects of SARs on clinically relevant domains are not yet well established. Our goal was therefore to provide a proof-of-concept demonstration of the capacity for SARs to alleviate clinically relevant symptoms in children. Such a demonstration might then serve as the foundation for efforts to establish the role of SARs in mental health care. We examined the influence of interactions with an SAR on mood, anxiety, and arousal in a sample of 87 children between the ages of 6 and 9, following exposure to a stressful task. Participants completed the Trier Social Stress Test for Children before interacting with the SAR, interacting with the SAR turned off, or waiting quietly. Participants completed baseline and posttest measures of state anxiety and mood, and salivary cortisol was collected at 5 time points. Children who interacted with the robot showed greater increases in positive mood than children in either of the two control conditions, but did not differ from control participants in terms of negative mood, anxiety, or arousal. SARs may convey benefits for children's mental health by augmenting positive mood. Future research should examine the processes through which SARs promote positive emotions and the circumstances under which that effect is most potent. Although preliminary, these findings suggest that SARs may provide a highly efficient way to alleviate clinical symptoms in children by increasing positive mood.

Public Significance Statement

The present study provides the first scientific demonstration of the use of a robot to improve children's mental health. After completing a stressful task, children in our study showed improvements in positive mood as a result of interacting with the robot. Robots may be useful for improving children's mood across a range of stressful circumstances, such as medical procedures and school assessments.

Keywords: anxiety, mood, socially assistive robot, intervention

Childhood disability related to mental illness is on the rise (Houtrow, Larson, Olson, Newacheck, & Halfon, 2014). Nearly 40% of Americans experience a diagnosable psychiatric disorder before age 17, and roughly half of all psychiatric disorders have first onset in childhood or early adolescence (Kessler et al., 2007; Merikangas et al., 2010). These estimates do not include the symptoms that precede full disorder onset, suggesting that the actual incidence of treatable childhood psychological problems is even greater (Kessler et al., 2007). Children with psychiatric conditions and subthreshold symptoms experience distress and impairment across domains, as well as reduced quality of life and increased risk for suicide (e.g., Balázs et al., 2013; Carter et al., 2010; Sawyer et al., 2002). However, less than half of children in need receive treatment (Merikangas et al., 2010). Scalable methods

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of reducing the burden of childhood mental health problems are sorely needed.

Advances in technology are likely to play a central role in efforts to scale up mental health interventions and reduce the burden of mental illness (Lal & Adair, 2014). Familiar technologies such as video conferencing, mobile applications, e-mail, and Web-based programs (e.g., chat-based interventions, interactive treatment modules) are already used widely to deliver mental health interventions (see Boydell et al., 2014, for a review). However, novel technologies are also being developed for this purpose and stand to make considerable contributions to efforts to reduce suffering among children. In particular, the emerging field of socially assistive robotics stands to make key contributions to efforts to reduce the burden of childhood psychiatric disorders in the 21st century.

Socially assistive robots (SARs) are robots that are designed to aid human users through social interaction (Feil-Seifer & Matarić, 2005). As the name suggests, socially assistive robotics falls at the intersection of assistive and social robotics. Assistive robots aid users, typically individuals with disabilities, in performing physical tasks that the individuals would not be able to perform independently. In contrast, social robots (also known as intelligent robots) do not necessarily provide aid to users, but instead have the primary goal of engaging socially with the user. Whereas assistive robots help without engaging, and social robots engage without helping, SARs use social engagement to help the user. Examples of SARs include Paro, a robotic harp seal intended to simulate the benefits of a therapy animal; Autom, a robotic weight-loss coach; and Keepon, a small interactive robot that is used to encourage joint attention and social engagement (Kidd & Breazeal, 2006; Kozima, Nakagawa, & Yasuda, 2007; Marti, Bacigalupo, Giusti, Mennecozzi, & Shibata, 2006). Although there are many familiar examples of interactive children's toys that are already prevalent in everyday life (e.g., furReal Friends, https://www.hasbro.com/en-us/brands/furreal; Cozmo, https://www.anki.com/en-us/cozmo), SARs differ from these toys in that SARs respond reciprocally and learn from their experiences, with the primary goal of providing aid to the child through their interactions, rather than serving as a form of entertainment or an educational tool.

SARs offer clear advantages for applications to mental health care (Rabbitt, Kazdin, & Scassellati, 2015). SARs are responsive, engaging, and motivating (Kidd & Breazeal, 2004, 2008; Torta, Oberzaucher, Werner, Cujipers, & Juola, 2012). SARs are also likely to be perceived as nonjudgmental, making them excellent candidates for providing social support. Indeed, some of the most common SARs are designed explicitly for this purpose. These "companion robots" are designed to fill a role similar to that of a therapy animal and provide an alternative to animals when there are concerns about contamination or infection transmission, safety, allergies to animals, fear of animals, or animal welfare (Crossman, 2017; Rabbitt et al., 2015). SARs are also easily transported and can be used in a wide range of climates and settings, meaning that they have the potential to be widely disseminated. Finally, SARs can be customized to encourage particular behaviors, integrate with existing technology, and produce maximum therapeutic change (Cabibihan, Javed, Ang, & Aljunied, 2013).

SARs have already taken on numerous roles in health care. For example, SARs provide patient education, aid in stroke rehabilitation by assisting with prescribed exercises, and coach patients through weight loss programs (Blanson Henkemans et al., 2013; Fasola & Matarić, 2010; Kang, Freedman, Matarić, Cunningham, & Lopez, 2005). Patients rate these robots as more enjoyable, useful, and helpful than digital programs that provide similar functions (Fasola & Matarić, 2010; Kidd & Breazeal, 2008). SARs have also begun to be incorporated into mental health care, where they are used to provide companionship, act as therapeutic play partners, and serve as coaches or instructors (Rabbitt et al., 2015). In this context, preliminary evidence supports the use of SARs for two primary populations—older adults who have dementia, and young children with autism spectrum disorder. Work with these populations shows that SARs are viewed positively, are effective at engaging patients, and produce improvements in domains such as mood, perceived social support, and quality of life.

Although encouraging, investigations of SARs in mental health care so far have been primarily exploratory (Rabbitt et al., 2015). As a result, these investigations have been characterized by important methodological limitations, including small sample sizes and lack of appropriate comparison conditions. In other words, the effects of SARs on clinically relevant domains are not yet well established. In addition, there is a wide range of clinical problems beyond dementia and autism that stand to benefit from SARs, but have not yet been tested. If SARs can be applied to alleviate suffering associated with other common childhood disorders and subthreshold symptoms, the potential impact would be considerable. What is needed are carefully controlled evaluations of SARs in which clinically relevant domains are assessed. Such evaluations will serve as the foundation for efforts to establish the effects of SARs.

Mood and anxiety symptoms constitute a useful domain in which to begin efforts to establish the effects of SARs in children's mental health care because these symptoms are prevalent, impairing, and tend to onset early in childhood (e.g., Costello, Mustillo, Erkanli, Keeler, & Angold, 2003; World Health Organization International Consortium in Psychiatric Epidemiology, 2000). In addition, improvements in mood and anxiety are important for subjective wellbeing and offer a path toward long-term mental and physical health (Chorpita, 2002; Folkman & Moskowitz, 2000; Fredrickson, 2003, 2004; Lyubomirsky, King, & Diener, 2005, p. 803). Even subthreshold symptoms and day-to-day fluctuations in anxiety and mood as a result of exposure to common stressors have important effects on overall health and wellbeing. In other words, SARs stand to make a considerable contribution to children's mental health by improving mood and alleviating anxiety.

There are also a number of theoretical reasons to believe that SARs are especially well suited to improving mood and anxiety symptoms. As noted above, many SARs (e.g., Paro, Aibo) are designed with the explicit purpose of mimicking the effects of therapy animals, which are used to target anxiety and mood more than any other symptom domain (Crossman, 2017). Drawing on the proposed mechanisms through which interactions with therapy animals improve anxiety and mood, it is likely that SARs may convey their effects by serving as a pleasurable activity and providing opportunities for positive reinforcement, promoting emotion regulation (e.g., distraction, recall of positive memories), providing social support by eliciting feelings of affiliation, and/or providing tactile stimulation (Crossman, 2017). This is not an exhaustive list, and the fact that SARs can be designed for specific purposes means that they may be customized to affect a wide range of processes related to mood and anxiety (e.g., inducing humor, aiding in cognitive reappraisal). However, these examples suggest processes through which existing SARs are likely to improve mood and anxiety and convey that mood and anxiety symptoms constitute a particularly promising domain in which to begin to establish the effects of SARs.

The purpose of the present study was to evaluate the influence of a brief interaction with an SAR on mood and anxiety in children. Our goal was to provide a proof-of-concept demonstration of the capacity for SARs to alleviate a class of clinically relevant symptoms that are prevalent, important for overall health and well-being, and commonly untreated in children. In line with our focus on providing a carefully controlled initial demonstration of the effects of an SAR, we elected to focus on establishing the immediate (i.e., short term) effects of the SAR on mood and anxiety following exposure to a moderate stressor, with the intention that the present evaluation will inform future efforts to establish the long-term effects of SARs. We predicted that interacting with an SAR following exposure to a stressful task would 1) increase positive mood, 2) reduce negative mood, 3) reduce state anxiety, and 4) reduce arousal.

Method

Participants

Participants were 87 children ages 6 to 9 ($M = 8.15$, $SD = 1.14$; 52.9% female, 47.1% male) drawn from the local community. Fifty-nine participants (67.8%) identified as White, non-Hispanic; 5 (5.7%) as Hispanic/Latino; 3 (3.4%) as Black/African American; 2 (2.3%) as Asian; and 18 (20.7%) as other.[1] Of the 101 participants who began the procedure, 14 did not complete the procedure and were excluded from the analysis. Participants did not complete the procedure for several reasons, including if they elected not to complete all aspects of the procedure or if the procedure was stopped early or substantially modified (e.g., allowing a parent to remain present during the procedure) to prevent excessive stress.

We elected to use a community sample considering the need for intervention methods that can reach a broad range of children. In addition, this was the first investigation to evaluate the use of an SAR to alleviate anxiety and mood symptoms in children, and our goal was to provide a proof-of-concept demonstration of this effect, rather than to establish the efficacy of the SAR on any full syndrome disorder. We elected to use this age group (6 to 9 years old) because of the long-term developmental impacts of anxiety and mood symptoms that occur during the early school years, as well as the relative paucity of interventions for anxiety and mood symptoms for this age group (Horowitz & Garber, 2006; Neil & Christensen, 2009). In addition, in our exploratory work with the SAR, younger children responded more positively to the SAR compared to older children. Our priority was to maximize the potential benefit of the intervention by focusing on younger children, while also ensuring that reliable and valid measures were available for assessing anxiety and mood in the age group.

Participants were recruited through a range of methods, including online advertisements, in-person recruiting at local museums and events, snowball sampling, and flyers distributed throughout the local community. In exchange for their participation, child participants were given a small toy, a certificate of participation, and a $5 gift card; parents of child participants were given a $15 gift card. This study was reviewed and approved by the institutional review board of Yale University.

Measures

Positive and negative affect. To measure positive and negative mood, we used the Positive and Negative Affect Schedule for Children, Short Form (PANAS-C-S). This self-report measure asks children the extent to which they feel 10 different feeling states "right now" (Ebesutani et al., 2012). Five of the 10 items assess positive affect, while the other five assess negative affect. Responses are made using a 5-point Likert scale, with options ranging from *very slightly or not at all* to *extremely*. The PANAS-C-S has demonstrated convergent and discriminant validity comparable to that of the full-length measure. Scores on the Negative Affect scale distinguish between youth with and without any anxiety or mood disorder, and scores on the Positive Affect scale distinguish between youth with and without mood disorders, as well as between youth with mood disorders and youth with externalizing disorders (Ebesutani et al., 2012). Cronbach's alpha was .81 for the Positive Affect scale and .84 for the Negative Affect scale at baseline in the present study.

The Positive and Negative Affect Schedule for Children—Parent version (PANAS-C-P) was also included to assess long-term positive and negative mood as possible adjustment variables (Ebesutani et al., 2012). The PANAS-C-P consists of 10 items mirroring those in the PANAS-C-S. Parents rated the degree to which their child had experienced each feeling "during the past few weeks." The PANAS-C-P has demonstrated internal consistency and construct validity (Ebesutani, Okamura, Higa-McMillan, & Chorpita, 2011). Cronbach's alpha was .81 for parent-reported positive affect and .75 for parent-reported negative affect in the present study.

Anxiety. State anxiety was assessed using the state portion of the State Trait Anxiety Inventory for Children (STAI-C). The STAI-C consists of 20 items, which ask the child to indicate how they feel "right now, at this very moment" (Spielberger, 1973). The STAI-C has demonstrated construct, concurrent, and discriminant validity (Kirisci & Clarke, 1996; Seligman, Ollendick, Langley, & Baldacci, 2004; Spielberger, 1973). Cronbach's alpha for the STAI-C was .86 at baseline in the present study.

Physiological arousal. Salivary cortisol was assessed as a physiological indicator of stress and anxiety. Salivary cortisol is a reliable measure of activation of the hypothalamic-pituitary-adrenal axis, which regulates the body's stress response (see Kirschbaum & Hellhammer, 1989, for a review). Child participants provided saliva samples by chewing on cotton SalivaBio Oral Swabs (Salimetrics, Carlsbad, CA) for 1 min at each of five time points. Children were instructed not to eat for an hour before coming to the lab, and the samples were stored at −20°C until they were shipped to Salimetrics Saliva Lab to be assayed. Samples were assayed in duplicate according to the manufacturer's recommended protocol (No. 1–3002, Salimetrics, Carlsbad, CA) using a highly sensitive enzyme immunoassay designed for analyzing saliva samples and a sample test volume of 25 μL of saliva per

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[1] The discrepancy in the total percentage is due to standard rounding.

determination.[2] The lower limit of sensitivity of the assay is 0.007 μg/dL; the standard curve ranges between 0.012 μg/dL and 3.0 μg/dL. The average intra-assay coefficient of variation in the present sample was 7.81%, indicating that cortisol concentration was assessed reliably.

Treatment of missing data. Sum scores were computed for all self-report measures. In cases where individual items were missing, missing data were prorated so long as the total number of items missing from a given measure constituted less than one quarter of the total items in that measure. Measures missing more than one quarter of the items were excluded. To prorate missing items, a mean score was computed using the completed items from that measure. Missing items were then substituted using that mean score, and the sum score was computed using completed and prorated items. Across each of our study measures, the average number of missing items per measure per person was less than one item.

Stress Induction

We predicted that interaction with the SAR would alleviate symptoms of stress. To induce moderate psychosocial stress, we used the Trier Social Stress Test for Children (TSST-C; Buske-Kirschbaum et al., 1997). In this task, participants are told the beginning of a story and are given 5 min to develop an ending to the story. Participants then present their endings to the story and complete a mental arithmetic task in front of two judges and a video camera. The judges smile and provide encouraging feedback to prevent excessive stress.

The TSST-C is a well-validated way to induce moderate psychosocial stress in children (Dickerson & Kemeny, 2004; Gunnar, Talge, & Herrera, 2009). The TSST-C has not yet been applied with children under the age of 7; however, 6-year-olds attend elementary school like their 7-year-old counterparts, experiencing similar social situations and pressures (National Center for Education Statistics, 2013). Before beginning the study, we piloted the TSST-C with 13 participants to ensure that the procedure induced the intended changes in physiological stress in our sample. Visual inspection of cortisol plots showed reliable increases in cortisol concentration following exposure to the TSST-C, with cortisol concentration beginning to decline between the third (5 min poststress exposure) and fourth (10 min poststress exposure) samples.

Conditions

Experimental condition. To test the predicted effects of the SAR, each participant in the experimental condition interacted with the SAR for 15 min after completing the TSST-C. The duration of the interactions was selected based on commonly reported durations of interactions with therapy animals (because many SARs, including the one in the present investigation, are intended to convey similar effects as therapy animals), based on our observations of children's interactions with the robot in naturalistic settings, and based on a desire to maximize the "dose" of the interaction, while also ensuring that waiting for an equivalent amount of time would not place an excessive burden on children in the waiting control condition (see "waiting control" section).

Participants were encouraged to pet, touch, and talk to the robot. Participants were left alone in the room with the robot and supervised through a two-way mirror. This unstructured format for the interactions was selected based on established paradigms for evaluating the effects of interactions with therapy animals on mental health, as well as common approaches to conducting interactions with SARs in other settings and populations (e.g., Crossman, Kazdin, & Knudson, 2015). The SAR used in this investigation was the Paro robot. The Paro robot is a 2.7-kg, 57-cm long robotic baby harp seal with off-white fur (Intelligent Systems Co., Ltd., Nanto, Japan; www.parorobots.com). Japan's National Institute of Advanced Industrial Science and Technology developed the Paro robot based on observations of live baby harp seals. The Paro robot responds to tactile stimuli sensed through its whiskers and contact sensors, responds positively to caressing, and possesses the ability to adapt its behavior according to its internal state. The internal state, which corresponds to a recognizable emotion, is altered by interaction and changes as time passes after stimulation so that the Paro robot's reactions are relevant to the situation (Marti et al., 2006). The Paro robot also responds to sound and knows its name (National Institute of Advanced Industrial Science and Technology, 2004).

Nonrobotic control. Our predictions were based on the expectation that the robotic nature of the SAR would benefit the child participants. In other words, we predicted that the experimental interactions would benefit the participants because of the robotic nature of the SAR. However, there are a number of other aspects of the SAR that might contribute to the predicted benefits. For example, the Paro robot is a novel object with soft fur, large eyes, and the appearance of a baby animal. Each of these characteristics might plausibly increase positive mood and/or reduce negative mood, anxiety, and physiological arousal (Karlesky & Isbister, 2014; McCarney et al., 2007; Morris, Reddy, & Bunting, 1995). To rule out these and other nonrobotic aspects of the SAR as alternative explanations for the predicted benefits, we included a nonrobotic control group. Participants in the nonrobotic control group interacted with the SAR while the robot was turned off and were not told that the robot had any robotic features.

Waiting control. It is possible that changes in mood, anxiety, and arousal could improve over time without intervention. For example, children's own coping skills, the comforting atmosphere of the playroom, or the fact that children completed the measures multiple times all might lead to change. To rule out these possibilities, we included a waiting control condition. Participants in this condition followed the same procedure as those in the other two conditions, but did not interact with the SAR (whether on or off) during this segment of the procedure. These participants were informed that they had a few minutes to relax before the next task.

Procedures

After informed parental consent and child assent were obtained, the parent completed a background questionnaire while the child participant began the procedure. After a 10-min acclimation period, the first cortisol sample was obtained, and the child completed the baseline PANAS-C-S and STAI-C, followed by the TSST-C procedure. Next, the second cortisol sample was obtained. The participant then began the 15-min intervention (experimental,

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[2] Because of an error, a portion of the samples (100 samples, representing 20 participants) were assayed in singlet, rather than in duplicate.

nonrobotic control, or waiting control). Assignment to participant condition was made using an online random number generator (Research Randomizer; https://www.randomizer.org/). Participants were randomized in sets of three (with one participant in each set assigned to each of the three conditions) to ensure that equal group sizes were maintained. After the 80th participant, assignment to condition was additionally divided based on participant sex (i.e., two copies of the output from the random number generator were printed; one for males, and one for females) to maintain similar numbers of male and female participants in each group. Experimenters administering the TSST-C were blind to participant condition. Cortisol samples were collected at 5-min intervals throughout the 15-min intervention, for a total of three samples during and after the intervention. After the last cortisol sample was obtained, the child completed the posttest PANAS-C-S and STAI-C. Participants in both control groups were then given an opportunity to interact with the robot with the robotic features turned on. Participants in the control conditions were debriefed, and each participant was provided a toy, gift certificates (child and parent), and a certificate of completion.

Results

Preliminary Analyses

We conducted preliminary analyses to evaluate whether participants in the three conditions differed on background or demographic characteristics. Chi-square tests revealed that participants in the three conditions did not differ significantly in terms of ethnicity or sex (*p*s = *ns*). One-way analyses of variance (ANOVAs) revealed that participants in the three conditions also did not differ in terms of age, parent-reported positive affect, or pretest measures of positive affect, negative affect, anxiety, or cortisol (*p*s = *ns*). However, participants did differ in terms of parent-reported recent negative affect, $F(2, 83) = 3.17$, $p = .047$, $\eta_p^2 = 0.07$.[3] Post hoc comparisons revealed that participants in the experimental condition had significantly higher levels of parent-reported recent negative affect ($M = 9.07$ $SD = 2.95$) than participants in the waiting control condition ($M = 7.39$, $SD = 2.33$), with a mean difference of 1.69 (95% confidence interval [CI] [0.01, 3.36], $p = .048$). There were no significant differences between parent-reported negative affect in the two control conditions or between the experimental and nonrobotic conditions. Descriptive statistics for parent-reported negative affect and all study measures are presented in Table 1.

We checked for redundancy of measures among our self-report measures at pretest using Pearson product moment correlations and a threshold of 0.71 (indicating a shared variance of 50%). Based on theory and evidence that negative affect is not merely the absence of positive affect, we expected that positive and negative affect would not be significantly correlated (Watson & Tellegen, 1985; Zevon & Tellegen, 1982). We predicted that negative affect and anxiety would be related but not redundant. As expected, positive and negative affect were not significantly correlated, $r(83) = .01$, $p = .92$. Also as expected, anxiety and negative affect were significantly correlated but not redundant, $r(82) = .36$, $p = .001$. Anxiety and positive affect were significantly negatively correlated, but not redundant, $r(82) = -.54$, $p < .001$.

Table 1
Unadjusted Means and Standard Deviations for Dependent and Adjustment Variables by Condition

Measure	Experimental condition		Nonrobotic control condition		Waiting control condition	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
PANAS-C-P						
Positive affect	19.44	2.53	19.11	3.00	20.19	2.39
Negative affect	9.07	2.95	7.86	2.53	7.39	2.33
Baseline self-report measures						
PANAS-C-S positive affect	18.81	6.18	17.72	5.99	18.00	4.65
PANAS-C-S negative affect	5.58	1.45	6.38	2.29	7.33	4.28
STAI-C	27.81	5.23	28.38	7.45	28.32	5.50
Posttest self-report measures						
PANAS-C-S positive affect	21.59	4.46	17.48	6.27	17.32	5.17
PANAS-C-S negative affect	5.30	.72	7.14	4.64	7.35	4.78
STAI-C	25.65	5.59	28.28	7.84	27.16	5.23
Cortisol (μg/dL)						
Baseline	0.08	0.04	0.07	0.03	0.08	0.04
$\mathrm{AUC_G}$	3.73	2.83	2.86	1.29	3.32	2.10

Note. PANAS-C-S = Positive and Negative Affect Schedule for Children; PANAS-C-P = Positive and Negative Affect Schedule for Children—Parent version; STAI-C = State Trait Anxiety Inventory for Children; $\mathrm{AUC_G}$ = area under the curve with respect to ground.

Effects of Interaction With the Robot

We predicted that interacting with the SAR would increase positive affect, reduce negative affect, and reduce state anxiety. To evaluate these predictions, we used a one-way analysis of covariance (ANCOVA) to evaluate the effect of the robot on each outcome measure, adjusting for baseline scores on that measure. We used this approach (rather than testing for an interaction between condition and time point) because participants completed the baseline measures at the beginning of the procedure (before the TSST-C), rather than immediately before the intervention. We used pairwise post hoc comparisons with a Bonferroni correction to probe significant effects. For post hoc comparisons, adjusted means and standard deviations are presented unless otherwise noted.

The one-way ANCOVA for positive affect revealed a significant effect of condition on posttest positive affect scores, $F(2, 81) = 7.01$, $p = .002$, $\eta_p^2 = 0.15$. Participants in the experimental condition ($M = 21.38$, $SE = 0.81$) had significantly higher posttest scores of positive affect than those in the waiting control condition ($M = 17.69$, $SE = 0.76$), with a mean difference of 3.68 (95% CI [0.97, 6.40], $p = .004$). Participants in the experimental condition also had significantly higher posttest positive affect scores than those in the nonrobotic control condition ($M = 17.74$, $SE = 0.77$), with a mean difference of 3.63 (95% CI [0.89, 6.37], $p = .005$). As predicted, participants who interacted with the robot following a stressful task showed significantly higher levels of positive affect than participants in either of the two control conditions.

In addition to increasing positive affect, we predicted that interacting with the SAR would reduce negative affect. In this case,

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[3] Standard benchmarks for partial η^2 are as follows: .0099 (small), .0588 (medium), and .1379 (large; Cohen, 1988; Richardson, 2011).

the results of the one-way ANCOVA did not reveal a significant effect of condition on posttest negative affect scores, $F(2, 81) = 1.04$, $p = .36$, $\eta_p^2 = 0.03$. This pattern of results held even when adjusting for differences in parent-reported recent negative affect, $F(2, 79) = 1.35$, $p = .27$, $\eta_p^2 = .03$. Participants in the different conditions did not show differences in change in negative affect.

We also predicted that interacting with the SAR would reduce state anxiety. Against our prediction, there was not a significant effect of condition on posttest state anxiety, $F(2, 81) = 1.03$, $p = .36$, $\eta_p^2 = 0.03$. Participants in the experimental condition did not show significantly different changes in anxiety over the course of the procedure compared to participants in the control conditions.

Our final prediction was that interaction with the SAR would reduce arousal, as measured by salivary cortisol. We evaluated cortisol output by computing the area under the curve with respect to ground (AUC_G; Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003). AUC_G provides a summary of overall cortisol output and considers change over time with respect to baseline scores, as well as the overall magnitude of the cortisol response. AUC_G is the most commonly used summary indicator of the cortisol response and is preferable to repeated-measures ANOVA because it considers variations in the time interval between measurements (e.g., 20 min between T1 and T2 vs. 5 min between T2 and T3 in the present study; Khoury et al., 2015; Pruessner et al., 2003). Results of a one-way ANOVA with condition as the independent variable and AUC_G as the dependent variable indicated that overall cortisol output did not differ significantly based on participant condition, $F(2, 83) = 1.15$, $p = .32$, $\eta_p^2 = 0.03$. Interacting with the robot did not reduce overall cortisol output over the course of the study.

Discussion

We found that brief, unstructured interaction with an SAR improved positive mood in children ages 6 to 9, and this effect was large in magnitude. Participants who interacted with the SAR showed greater increases in positive mood compared to those in the two control conditions. From these findings, we can conclude that experience with the robot, rather than some other appealing feature of the robot (e.g., that it is soft), or some aspect of the procedure produced the increases in positive affect.

We did not detect an effect of the SAR on negative mood, anxiety, or arousal. However, our findings are in line with emerging evidence on the benefits of therapy animals, which suggests that the strongest effect of therapy animals is to increase positive mood, rather than to reduce negative mood or anxiety (e.g., Collins et al., 2006; Crossman, 2017; Crossman et al., 2015). As in the case of therapy animals, interventions with SARs may convey their therapeutic benefits by augmenting positive mood, rather than by reducing anxiety or negative mood. This effect is notable, because positive mood has been identified as “the hallmark of well-being,” (Lyubomirsky et al., 2005, p. 803) and low levels of positive mood are a key characteristic of childhood depression (Chorpita, 2002; Folkman & Moskowitz, 2000; Fredrickson, 2003, 2004). Even short-term changes in positive mood have documented benefits for mental health (Fredrickson, 2001). If SARs can increase positive mood in young children, populations who would especially stand to benefit from SARs include children with elevated internalizing symptoms, children exposed to acutely stressful situations (e.g., severe injury or illness, parental divorce), and children facing everyday stressors.

This study bears two key limitations. First, we examined only short-term changes in anxiety, mood, and arousal. We elected to use this design for our study in light of the lack of previous research in this area. Our goal was to provide a proof-of-concept demonstration of the influence of an SAR on anxiety and mood, rather than to establish the nature of the long-term benefits. A second limitation to the present study is that children had only brief interactions with the SAR. Again, this was a targeted choice to explore the effects of interactions similar in duration and style to those used with therapy animals, and to provide a proof-of-concept evaluation. However, it is possible that a longer interaction would reveal effects on negative mood, anxiety, or physiological arousal that were not produced by the interactions in our investigation.

Future Directions

There are a number of key areas for future research on the effects of SARs on children’s mental health, with two that we see as special priorities. First, a key question is how the SAR increased positive mood. Our inclusion of a nonrobotic control suggests that it is not merely that the robot is soft or that children find it to be cute that produces increases in positive mood. Instead, it might be that the robot is responsive, that the robot encourages physical contact, that children find the robot humorous, or any number of other attributes of the robot that produced the increases in positive mood. However, it is possible that the novelty of the robot contributed to this effect, and isolating any effect of this novelty from other effects will be important in ensuring that the effects of SARs do not “wear off” after only a few uses. Identifying what it is about interaction with the robot that produces the benefits will shed light on how those benefits can be enhanced or leveraged (e.g., by explicitly instructing children to pet or talk to the robot). Information about how the SAR improved mood might additionally be used to inform the design of future generations of the Paro robot and of other SARs, so that they can be designed specifically to maximize their effects on positive mood.

A second area for future research is to identify for whom and under what circumstances SARs are most effective. For example, we selected the age group for this investigation based on a combination of the population we predicted would benefit most and the availability of valid and reliable measures for that population. However, it is possible that the robot might be more developmentally appropriate for younger children. In contrast, older children and children who have exposure to sophisticated toys and technology may find the SAR less compelling. Another factor that might influence the effects of the SAR is whether children interact with the SAR individually or in groups. A frequently cited benefit of therapy animals is that they facilitate interactions (Crossman, 2017). The SAR may play a similar role, prompting children to interact with each other, as well as with the robot itself, when the interactions are conducted in groups. Finally, we evaluated the capacity of the SAR to ameliorate the consequences of exposure to a stressor, after levels of anxiety and mood were already elevated. It might be that the SAR has a stronger effect as a preventive intervention, buffering against the negative effects of anticipation of and exposure to stress, and even improving performance during the stressor. To use the therapy dog analogy, although therapy dogs are commonly used to ameliorate symptoms after exposure to a stressor (e.g., after a tragedy or natural disaster), they are also commonly used to reduce anxiety and improve mood in advance of exposure to a stressor, such as before an upcoming school exam or before a surgical procedure. Identifying the participant characteristics, intervention formats, and other factors that allow SARs to produce the greatest improvements will be crucial to maximizing the benefits of SARs.

Implications and Applications

Childhood mental illness and subthreshold symptoms are responsible for considerable distress and disability, but at this point, less than half of children in need receive any kind of treatment. Although preliminary, our findings support the idea that SARs may play a key role in efforts to reduce suffering on a large scale. We found specific evidence to support the idea that SARs, such as the Paro robot used in our investigation, may be used to increase positive mood. This effect is notable in light of the established role of positive emotions in promoting physical and mental health and well-being. In addition, this effect suggests that SARs may have a particular role in addressing symptoms of childhood depression, which is characterized by low levels of positive mood, in addition to the presence of negative mood (Chorpita, 2002; Clark & Watson, 1991).

SARs may be used to promote positive mood in a wide range of settings including schools, libraries, airports, and pediatricians' offices. Trained therapy animals are already used in these settings, and SARs may further expand the reach of this type of intervention. We do not wish to suggest that therapy animals and SARs are likely to have precisely the same effects or roles. However, our findings suggest that SARs may provide an efficient way to increase positive mood in children, which is in line with findings on one benefit of interactions with animals. SARs may also be used in settings where therapy animals are typically not allowed, such as intensive care units or settings where there would be concerns about animal welfare. Finally, SARs may be used with children who cannot interact with therapy animals because of allergies to or fears of animals.

In addition to specific evidence for the effect of SARs on positive mood, our findings provide a proof-of-concept demonstration that SARs can affect clinically relevant symptoms in children. Future studies may establish the use of a of SARs to address a wide range of clinical problems and symptoms, beyond those examined in our investigation. Examples of other promising areas for the application of SARs in children's mental health care include providing stimulation and social support to children in institutional settings (e.g., orphanages), administering behavioral interventions for children with conduct problems, and facilitating engagement in psychotherapy. What is more, as robotic technology continues to develop and SARs become more integrated and accepted in everyday life, the range of potential applications of SARs will also expand. In this way, SARs may play a key role in efforts to reduce suffering and impairment associated with childhood mental illness.

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