Loving-kindness and walking meditation with a robot: Countering negative mood by stimulating creativity

Highlights

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Valence is positively correlated with state openness, and both stimulate willingness to create.

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Audio-guided Loving-Kindness Meditation (LKM) and Walking Meditation (WM) improve state openness, while audio-guided LKM led to a positive change in valence as well.

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State openness rather than improved valence contributes to better performance on convergent thinking.

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Robot affordances should be designed according to the goals of the task.

Abstract

Young adults undergoing psychological changes are particularly vulnerable. Recent social isolation impedes interpersonal help while

stress from family, school, work, and society has brought negative effects on mental health, even in otherwise healthy young adults. Recent research has shown that daily creativity contributes to well-being. To circumvent issues of contamination, we tried a NAO robot guiding a Loving-kindness Meditation (LKM) and Walking Meditation (WM). By improving mental states (i.e. positive valence and state openness), we stimulated creative behavior to reduce negative mood. Participants (N = 142) were healthy individuals, aged between 18 and 34, joining a one-time laboratory experiment. They responded to two rounds of questionnaires, with a 10 min intervention guided by audio or a NAO robot in between each round. A control group with participants with no treatment (i.e. taking a 10 min rest) was added for comparison. Both audio-guided LKM and WM successfully evoked state openness, with the former also exerting a positive effect on valence. Valence and state openness were positively correlated, and both were associated with a higher willingness to create. With positive valence, young adults likely perform better on convergent thinking. The result may potentially lead to negative mood reduction. The discussion emphasizes the importance of designing specific characteristics of social robots in accordance with the task's context.

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Keywords

Social robot

Daily creativity

Meditation

Mental health

State openness

1. Introduction

Young adults in Hong Kong experience stress from family, school, work and society. Continuously experiencing negative emotions can lead to mood disorders, even in otherwise healthy individuals. A report on mental health among Hong Kong university students (Lun et al., 2018) revealed that 68.5% of university undergraduates show depressive or anxiety symptoms. The COVID-19 pandemic has aggravated existing problems. People reported deteriorated mental health in the population (Choi et al., 2020; Hou et al., 2021; Wong et al., 2022a). Restrictive measures, such as school suspension and dine-in ban increased the time spent at home and alone, bringing significant negative impact to day-to-day momentary affect (Wong et al., 2022b).

With proper intervention, there can be improvement of young adults' well-being. However, the pandemic limited the opportunities for seeking help from professionals in clinics, schools or health centers. Worse still, young people are the largest group of mental-healthcare avoiders among all ages (Lun et al., 2018; Martínez-Hernáez et al., 2014). Recovery is hampered, due to stigma, a lack of therapists (He et al., 2021; Lun et al., 2018), unfavorable help-seeking attitudes, and patient disengagement with mental healthcare (Do et al., 2021).

To address these issues, researchers are starting to look into the possibilities of providing support to young adults, even when there is physical social isolation. Utilizing social robots to promote participation in at-home interventions is a potential solution. Robots are portable and could be flexibly applied in different locations and times. Duan et al. (2021) show evidence that young participants who experienced intense negativity preferred to self-disclose to robots

over writing down their experiences. Negative affect reduced after talking to the robot. A follow-up study compared self-disclosure on social media, writing a diary, or talking to a robot (Luo et al., 2022). Again, participants benefited the most from robot intervention. Robots provide direct interaction but do not invite social comparison nor do they exert peer pressure. Previous Human-Robot Interaction (HRI) studies propose that the feeling of co-presence with an embodied therapy agent could enhance motivation and performance while creating a joyful interaction (Anupama et al., 2014; Tapus et al., 2009). With responsible design, social robots can assist young adults with carefully devised mental-health interventions.

The use of social robots should be studied separately in different populations (Scoglio et al., 2019). Many studies into social robots and mental health focus on the elderly (e.g., Chen et al. 2018, Khosla et al. 2017, Rau 2017, Pu et al. 2019). Some used mental health outcomes as a secondary focus (Scoglio et al., 2019). Little is known about their potential use in improving the psychological well-being of young adults. They are at the age that they have to identify personal trajectories, cope with complicated contextual factors, and be open to changing their life plans and conditions (Sica, 2022), robot intervention design should take these into consideration. Compared to other methods like lifestyle apps or human trainers, little guidance exists on the design of robot interventions for mental health (exception being Laban et al., 2021). With our study on improving young adults' mental health, we want to contribute to the possible use of social robots in the area.

The Broaden-and-Build Theory (Fredrickson, 2001) provides our first source of inspiration. It states that positive emotions and openness to the world build up personal resources to cope with future setbacks. Positive emotions broaden thinking, encourage exploration, build resources, and lead to thriving and resilience.

These further bring optimal well-being. However, research (Petty and Briñol, 2015) also suggests that positive emotions can sometimes lead to complacent or less vigilant thinking, people could be less receptive to new information that challenges their existing beliefs. For the broaden-and-build effects to flourish, positive emotions should be accompanied by openness. The second source is from Richards (2007), who proposed that everyday creativity fosters and reflects psychological health. People feeling happy are more likely to join creativity-related activities (exploration) at the time; when people regularly engage in creativity-related activities, they could be psychologically healthier. With these two theories, we develop the insight that everyday creativity can serve as a pathway to achieve the Broaden-and-Build effect, positive emotions and openness are the catalyst for upward spirals of well-being.

Specifically, young adults require fluency and flexibility to provide diversified solutions and insight, so as to cope with changing events in their developing trajectories. Knowing that being positive and open-minded are common characteristics of a creative person (Csíkszentmihályi, 1996, pp. 52–53), we developed the idea to reduce young adults' negative mood by enhancing their everyday creativity.

Following that, we targeted interventions that would facilitate state openness and positive emotion (i.e. in terms of valence).
Totzeck et al. (2020) indicated that meditation is a stress reliever and thus could be an option. Meanwhile, we used at-home social robots to motivate that pursuit. We investigated the possibility of using robots to lead a so-called Loving-kindness Meditation (LKM) and a Walking Meditation (WM) to make young adults more open-minded and positively valenced, stimulating creative behavior while de-escalating negative mood.

2. Related work

2.1. Mental health

Mental health is a state of psychological well-being that enables people to cope with stress, actualize their potential, live well, and contribute to the community (World Health Organization, 2022). Good mental health is essential for overall health and quality of life, as it is closely associated with physical health, personal relationships, and occupational functioning (Keyes, 2005).

Persistent negative emotions may result in mental health problems or mood disorders such as depression and anxiety (World Health Organization, 2021a, 2021b). In Hong Kong, a local survey indicated that nearly half of the respondents exhibited symptoms of mild to severe depression (Mind HK, 2022). Kessler et al. (2005) found that 75% of mental health problems tend to emerge during an individual's twenties. Young adults are particularly susceptible to mental health issues due to the numerous physical, emotional, and social transitions they undergo during this stage of life (Arnett, 2000), which can impede individuals' capacity to lead fulfilling lives and create risks for themselves, their families, and their communities.

Kabat-Zinn (2003) suggested that engaging in mindfulness meditation, deep breathing exercises, or progressive muscle relaxation can help individuals cultivate resilience. These practices promote self-awareness, emotional regulation, and a more balanced perspective on life's challenges. Nowadays, the field offers blended treatments, self-help programs, or multimedia-delivered exercises, which have the potential to create more approachable alternatives to the traditional face-to-face approach (Davies et al., 2018). It inspires further research on digital self-help guides for vulnerable young people to maintain mental health. Such interventions may offer

accessible, cost-effective, and evidence-based support for promoting mental well-being in this at-risk population. Adding to multimedia-delivered meditation and digital self-help guides, we study the reduction of negative mood through robot-guided intervention.

2.2. Emotion, mood, and valence

The literature distinguishes between emotions and moods. Emotion is a complex matter involving feelings, physiology, cognition, expression, and behavior (Frijda, 1988; Sonnemans and Frijda, 1995). Emotions of the same polarity can differ greatly regarding their underlying causes and thus affect people's judgment and behavior in different ways. For example, sadness, usually classified as a negative emotion, can sometimes foster creativity while also inhibiting it. Moreover, the accuracy of measuring emotions by self-report has, at times, been called into question. Most people have a difficult time pinpointing specific reasons for their attitudes and actions (Krosnick, 1988). Given the limited availability of vocabulary, people may find it difficult to report complex emotions in a questionnaire.

Moods and emotions are differentiated by intensity and duration. While emotion is an instantaneous perception of a feeling that can be over in just a few seconds (Ekman, 1984), mood has a lower intensity and is long-lasting (Santos et al., 2011). Prolonged and persistent low mood can impair daily functioning, and cause negative thinking patterns and social isolation. These factors may exacerbate existing mental health conditions and lead to mental illness.

Valence is an inferred criterion in which the (positive or negative) evaluation of intentional objects is presented by emotions (Vazard, 2022). It is an affective action tendency towards a situation,

person, or event based on goal attainment (positive) or non-attainment (negative) (Frijda, 1986. p. 207). That tendency may be to approach and feel attracted towards an entity (positive valence) but also may indicate avoidance, repulsion, towards an entity (negative valence), which typically is accompanied by anger and fear. People may experience a mix of both positive and negative valence, indicating a state of being ambivalent.

2.3. State openness

Openness to new experiences is conceptualized as a broad personality trait (McCrae, 1993) and indicates how an individual typically deals with novel stimuli (Peterson and Carson, 2000). Not surprisingly, numerous research efforts have been devoted to investigating its correlation with important outcomes in life, including creativity (Kaufman et al., 2016), intelligence (Schretlen et al., 2010; Ziegler et al., 2012), good relationships (Barańczuk, 2019; Zhou et al., 2017), and well-being (Dong and Ni, 2020; Furnham and Petrides, 2003). Yet, these studies merely reveal that people who are spontaneously open to new experiences and who continue to be so throughout their lives achieve better outcomes.

Recent studies recognized that personality traits show development patterns and changes in response to life events (Bleidorn et al., 2018), interventions (Roberts et al., 2017), and goals (Hudson and Roberts, 2014). State openness is the momentary expression of the trait. States can be influenced by the situation that one experiences (Fleeson and Jayawickreme, 2015), and reflect their current thought, feelings, and behaviors. This implies that continuous participation in practice that facilitates state openness would eventually affect *trait* openness.

While engaging in the act of creation, we focus on the effect of

elicited openness rather than trait openness. A creative pursuit entails both idea and action, which is why we operationalize elicited openness as a state: Being open to receiving information while freely thinking.

2.4. Everyday creativity

The creative process necessitates both divergent and convergent thinking (Guilford, 1950). Divergence is a style of thinking that allows multiple ideas because more than one solution can be correct. Convergence is the process of finding the unique answer to a well-defined problem (Colzato et al., 2014). Sica (2022) identified creativity as an individual psychological resource for young adults' well-being with seven functions (i.e., cope with difficult times, conduct tangible problem-solving, withstand unpredictable changes, engage in self-expression, help others, benefit from the creativity of others, and conduct narrative meaning-making). Kapoor and Kaufman (2020) also suggested that creativity can be used for the function of meaning-making during an unexpected event, such as the COVID-19 lockdown.

Ilha Villanova et al. (2021) proposed that everyday creativity can be conceptually defined as "a phenomenon in which a person habitually responds to daily tasks in an original and meaningful way." With that, we do not hinge on breakthrough creativity that changes a society but on everyday creativity as a type of self-expression, such as avocational pursuits and problem-solving in people's everyday lives (Ivcevic, 2007).

"Willingness" is a crucial prerequisite to creative action (Ogbeibu et al., 2021). With the willingness to be creative, one obviously is more likely to participate in the production of creative outcomes. Unlike artistic activities or Big-C inventions

(Csíkszentmihályi, 1996) that demand a high level of inventiveness, daily creative activities allow everybody to participate and benefit. Everyday creative behavior can serve as the cause and effect of positive psychological processes. People feel happy and active while doing something creative, it can be as simple as drawing, making recipes, or writing (Silvia et al., 2014). Young adults who experience negative mood may benefit psychologically from engaging in creative acts (Conner et al., 2018; Richards, 2007).

2.5. Relationship between emotion, mood, (state) openness, and everyday creativity

The Broaden-and-Build Theory (Fredrickson, 2001) suggests that positive emotions such as joy, gratitude, and love have the power to "broaden" an individual's thought-action repertoire. They expand one's attention and awareness, which allows more possible thoughts and actions to come to mind. The broadened inventory of thoughts and actions builds useful skills and psychological resources that enhance resilience to cope with stress in the future. In the long run, it improves overall mental health. In our conceptual framework, we postulate that both positive valence and state openness can facilitate the broadening effects, which in turn may reduce negative mood through engagement in everyday creative pursuits.

State openness is a momentary expression of the trait. Recent research suggests that recalling positive, novel, and nostalgic experiences can increase state openness (Hotchin and West, 2020). The joyful moments increase the confidence about future exploration. That can eventually affect trait openness and facilitate the positive connection that it brings.

Positive emotions open one's mind. In investigating the effect of emotion on the scope of attention and thought-action repertoires,

Fredrickson and Branigan (2005) designed two experiments with 104 college students. Positive emotions broadened the scope of attention and thought-action repertoires whereas negative emotions narrowed thought-action repertoires in comparison to a neutral state.

Openness is oppositely related to negative moods.
Antinori et al. (2017) found that open people are more perceptive to the presentation of multiple stimuli. They studied 234 participants for binocular rivalry - where contrasting stimuli are presented at the same time to each eye and observers report the stimuli that they see. Those high on openness have more flexible gates to let through more information than the average. Open people seem more motivated to explore the world and engage in possibilities. They understand others rather than being understood, which avoids negative moods such as frustration and disappointment.

Positive emotion and openness have a close relationship to everyday creativity. A systematic review by Jovanovic et al. (2016) indicated that positive emotion is the most prominent aspect in acts of creativity. The approach motivation and promotion focus generated by positive emotions enhance creativity (Baas et al., 2008).
Langley et al. (2018) found evidence that positive emotions correlated with a higher creative output than negative ones. Positive emotions increase the levels of perceived creativity as well as the quality and quantity of creative output. Negative emotions are more likely to result in a more careful and systematic behavior, but threat states may reduce one's willingness to take up challenges, collaborate, and share ideas.

Based on assessments of divergent thinking, openness is correlated with everyday creativity (McCrae, 1987). Openness allows more access to the information universe and increases the possibility of

connecting unrelated domains (Hoorn, 2014), leading to unique, creative results. The latest studies also found that intrinsic motivation has a mediating role in the relationship between openness and creativity (Tan et al., 2019; Watanabe et al., 2011). People who score high on openness to experience have high intrinsic motivation, which enhances engagement in creativity-related activities, and eventually improves creativity. The creative process is replete with emotion - from curiosity about a new undertaking to frustration at dead ends to the joys of a completed product - these emotions have to be regulated to support creative behavior (Ivcevic and Brackett, 2015).

Yet, how does creativity facilitate the generation of positive moods? Conner et al. (2018) invited young adults to participate in a 13-day daily study. After creative activity, participants felt more positive and reported to 'flourish,' which the researchers linked with flow states. In a week-long study with 79 university students (Silvia et al., 2014), the happier participants were those who engaged in creative activities. Engaging in creative pursuits lets people explore identities, form new relationships, and cultivate competence. That way, people would gain new knowledge, self-insight, and build relationships with others, which are sources of strength and resilience that help reduce depression.

By contrast, lower creativity is associated with more negative moods. Kircaburun et al. (2018) investigated 460 Turkish adults aged 18 to 26 for the link between creativity and Problematic Social Media Use (PSMU). People with a lower level of creativity tended to face difficulties in social interaction. They avoided responsibility and real-life interaction, leading to a higher feeling of depression and higher chances for PSMU. Even stronger evidence was reported by Bell and Robbins (2007), who had 50 adults aged 18 to 30 do different art interactions. Negative mood was strongly reduced in those who

created art as compared to those who just viewed it. Alfonso-Benlliure and Meléndez Moral (2022) found that developing divergent thinking can help to reduce negative moods. It helps to minimize negative self-focuses. Getting more information from multiple perspectives avoids focusing on self-blame, self-block, and other negative internal dialog. On the other hand, improving convergent thinking is also a possible method. Chiu et al. (2019) indicated that insight reappraisal can induce insight experience and enhance cognitive changes, eventually reducing negative emotional responses.

To cultivate psychological resources that can bolster mental health, being in a state of positive valence and openness could be necessary to initiate the process. Positive valence and state openness appear to prime individuals for the willingness and ability to engage in creative activities. Pursuing everyday creativity can further strengthen the effects of these states and contribute to resource accumulation in the long term, which in turn contributes to reducing negative mood and promoting well-being. Although creativity has been seen as an important individual resource for young adults (Sica, 2022), literature that links these factors together is scarce. Researchers do not try creativity as a 'bridge' for intervention design. In our current attempt, we make use of the link between positive emotion, state openness, and everyday creativity to reduce negative mood in young adults by means of a robot-guided intervention.

2.6. Meditation intervention

Meditation is seen as a stress reliever (Totzeck et al., 2020) and a simple indirect method to train creativity. Ding et al. (2015) studied mood and short-term integrative body-mind training (IBMT). After receiving 30 min of IBMT for 7 days, students showed significantly

greater creative performance. A decline in depressive, angry, tired, and introverted feelings, caused by improved emotional stability and vigor, accounted for the changes. Henriksen et al. (2020) state that mindfulness interventions expand awareness in a non-judgmental way. The decrease of fear would be associated with presenting novel ideas.

Specifically, Loving-kindness Meditation (LKM) can help generate positive emotions (Fredrickson et al., 2008; Lindsay et al., 2018; Totzeck et al., 2020; Zeng et al., 2015), which are required to build a bank of personal resources (Fredrickson and Branigan, 2005; Fredrickson et al., 2008; Oishi and Kurtz, 2011). People engaging in LKM first imagine a person or a group of other people and then imaginatively spread love and kindness to them. That way, they become mindful, pay attention to the present moment, and focus on their thoughts and feelings or external sensations. This kind of practice is recommended by several National Health Service bodies in the UK to reduce the risk of relapse in people with depression.

Walking Meditation (WM) blends meditation with the physical experience of walking. A walk in the park may be beneficial for mental health, reducing state anxiety, although mixed results are reported as well (Kotera et al., 2021). What we know is that not being sedentary and doing exercises in itself is effective for improving mental health, although again, robust evidence is missing (Pascoe et al., 2020). Oppezzo and Schwartz (2014) showed that the act of walking, no matter if it is indoor or outdoor, could encourage the free flow of ideas and promote openness. In other words, walking inside may be just as valuable as going outside and for purposes of control and excluding confounds of external factors, we kept participants within the confines of the lab.

We will use both types of meditation to induce state openness and

positive valence. However, unwanted negative effects of meditation have also been reported. Farias et al. (2020) found instances of psychosis or suicidal ideation during solo meditation. The mind 'rebels' when people try to silence their thoughts. The researchers suggested that patients may opt for guided exercise. The present study intends to apply a social robot as an instructor to guide the meditation and the walking exercise.

2.7. Robot intervention

Successful cases of robot usage are found in depressed older adults. A recent meta-analysis (Lee et al., 2022) states that using artificial intelligence robots can assist in providing therapy, counseling service, conversation, etc. to improve the quality of care for the elderly and prevent the overload of caregivers. Interacting with Paro, a harp-seal robot, can improve the elderly's mood and reduce depression (Wada et al., 2004). Abdollahi et al. (2017) showed that depressed older adults accepted robots as a companion and their interest in the robot did not decay over time.

However, there is relatively less research about the application of robots in younger groups. Below are some cases that could be related to the topic.

To solve social isolation problems, Jeong et al. (2018) built Fribo, a sound-based social networking robot for sharing daily home activities with friends. The results show that Fribo reduced the feeling of loneliness and triggered more frequent real-world social interactions.

Regarding mental health, Alves-Oliveira et al. (2022) did a try-out in creating a digital robot agent that delivered micro-interventions related to mental health. Compared to a physical workshop,

participants found it preferable and engaging in joining treatment delivered by a robot. The results align with Duan et al. (2021), revealing that young participants with intense negative mood chose to self-disclose to robots over writing down their experiences. Young adults feel safe in their sharing with robots because they know that the robot does not judge (Alves-Oliveira et al., 2022).

Researchers also investigated the possibility of enhancing creativity with social robots among young adults. Alves-Oliveira et al. (2019) designed a collaborative drawing task for university students. The robot acted as a peer in the activity, taking turns with the participants, to complete the drawing. No significant improvement was found in the creativity scores. Researchers suggested that the results may come from the mismatch of task and young adult users' expectations: Participants did not want the robot to disturb their creation and they expected better drawing ability of the robot. A more effective case came from Kahn et al. (2016). They designed a Zen rock garden for forty-eight undergraduate students and used the robot Robovie to pull relevant images and videos to encourage participants to generate creative ideas. Compared to a self-paced Powerpoint presentation, participants engaged in the creativity task longer with the robot and provided more creative expressions. Participants were interested in the social presence of an embodied humanoid robot with additional language cues and interaction.

Surely, robot aid is not to replace human professionals but may provide alternatives to assist existing practices and improve people's lives. With proper design, the existing cases show the potential of applying robot intervention to reduce negative mood and stimulate creativity among the young population. Young adults may be eager to try out new technology and so a robot-guided intervention may be a fun way for them to have accessible guided treatment at home.

3. Research question and hypotheses

In the preceding section, we explicated the interplay among positive emotion, state openness, and everyday creativity. Walking and loving-kindness meditation are potential interventions for inducing states of openness and positive valence, which encourage young adults to engage in daily creative pursuits. We propose using robots to guide these interventions. Over time, sustained small creative actions would extend the duration and potency of being in positive and open states. This builds useful psychological resources to bolster resilience and stimulate a healthy psychological state.

Research questions are (i) whether positive valence and state openness boost creativity and eventually reduce negative mood; (ii) whether robots facilitate those effects. From these questions, the following hypotheses are derived:

LKM and WM evoke positive valence (H1) and state openness (H2), which correlate with each other (H3). With higher levels of positive valence (H4) and state openness (H5), creativity will be improved in terms of willingness and capability to create. Robots, compared to mere audio, have a positive moderating effect on the relationship between treatments on valence (H6a) and state openness (H6b).

In this regard, engaging in creativity-related activities will further reduce negative mood (H7). Particularly, the final state of negative mood correlates with positive valence (H8) and state openness (H9) that emerges after meditation. Lastly, negative moods have a negative impact on creativity (H10).

The overview of our hypotheses is offered in Fig. 1. The arrows with solid lines are our focus of the model. Dotted lines are other possible relationships that might be found. Note that H7-H10 require

longitudinal study for possible significant changes to emerge. For reasons of feasibility, in this study, we only test H1-H6 in a one-off experiment. Tested parts are shown in a bolded box in Fig. 1.

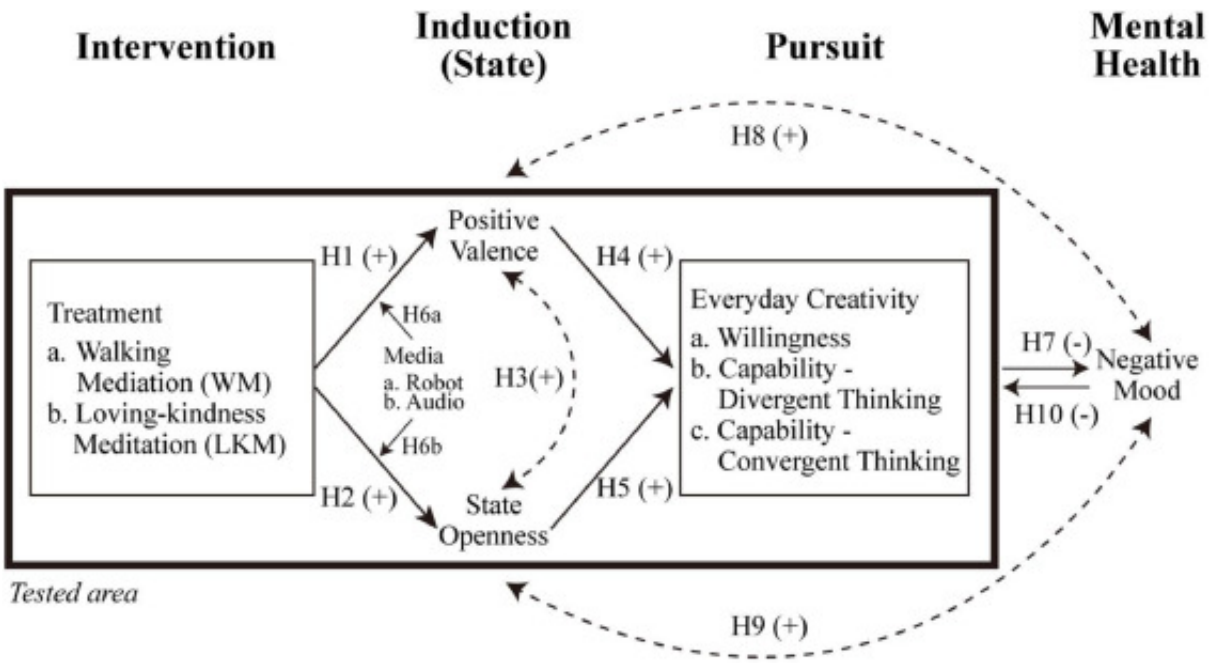

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Fig. 1. Effect of induced state openness and positive valence on reducing negative mood.

4. Pilot study

Before designing the actual experiment, a pilot study was conducted to test questionnaire items, procedures, and potential confounds. We wanted to know i. whether doing nothing would yield the same results as active intervention; ii. whether the order of completing the two creativity-capability tests would affect the results.

4.1. Pilot participants

Forty-four participants, aged 18–35, were randomly distributed over five conditions (i.e. WM × Robot; WM × Audio; LKM × Robot; LKM × Audio and the control group - Rest).

4.2. Pilot study design

The pilot experiments were held at-home with links provided. Participants were required to complete the tasks in a quiet indoor area with their own digital devices. A structured questionnaire with 5 constructs was tested before and after the intervention: emotion (*Emo1, Emo2*), open-mindedness (*Open1, Open2*), willingness to create (*Will1, Will2*), capability to create - divergent thinking (*AUT1, AUT2*), as well as convergent thinking (*RAT1, RAT2*). At the end of the questionnaire, manipulation and demographic data were collected as control factors.

All WM groups did a walking exercise with a park-scene video. Participants walked on the spot in a place where they found comfortable moving their bodies. LKM groups were given a video that guided them to spread love and kindness. For both WM and LKM groups, instruction was given by voice (audio only) or by a robot instructor on-screen. In the control group, participants were guided to sit still and take a rest for 10 min.

4.3. Result

Detailed analysis and results of the pilot study can be found in the Technical Report (see Supplementary materials). Here, we list out the summary of our findings:

1

We used a control group to see if taking a rest offers similar results to WM and LKM. We conducted repeated measures GLM Multivariate Analysis (MANOVA) to find that *treatment* had effects on most of the variables, including positive emotion, open-mindedness, willingness to create, although the type of *treatment* did not matter.

Thus, treatment made no difference compared to doing nothing.

2

To find out whether the order of completing the AUT and RAT made a difference, we ran the GLM Multivariate on all *z*-scores with *treatment* and *media* as fixed factors, using order of completing the test (*first-second*) as the covariates. The results showed no significant effects for all measures. Other attributes, including gender, age, the highest education level and region did not affect the result.

4.4. Conclusions on the pilot

Firstly, we could not eliminate the influence of idle time. Ten minutes of no matter what activity, including taking a rest, were not more or less effective. In the main experiment, then, we included a control group that received no treatment (i.e., they took a rest).

Secondly, the order of completing the two capability tests did not affect results, so we do not regard order of task completion as a confounding variable.

Thirdly, we had to better balance the emotion scale, which had but 2 positive against 10 negative items. We also removed 5 out of 8 items from the open-mindedness scale, owing to weak convergent reliability.

5. Main experiment: materials and methods

5.1. Participants

This study was conducted during the COVID-19 pandemic in Hong Kong SAR with strict measures of social distancing and severe

restrictions on travel. The number of young adults feeling lonely and sad increased dramatically (cf. Bu et al. 2020a, Bu et al. 2020b, Killgore et al. 2020, Li and Wang 2020, Tso and Park 2020). It is the time that managing stress and building resilience become important, even in otherwise healthy young adults. We opted for a large enough pool of experiment participants who yet showed signs of negative mood. Our volunteers were young adults (N=142; $M_{(age)}$ = 23.03, $SD_{(age)}$ = 4.48, 55.6% male, 64.8% Hong Konger), recruited through advertisements posted at the university and online: Facebook, Instagram, Dcard, and Gööp.

We conducted an experiment with a 2 (*treatment*: WM vs. LKM) × 2 (*media*: Robot vs. Audio) factorial design with 1 full control condition: Rest. Participants were randomly distributed over the conditions (i.e., WM × Robot; WM × Audio; LKM × Robot; LKM × Audio and the control group - Rest). A pretest-posttest design was adopted for this experiment. Before and after the intervention, participants completed a set of questionnaires to measure valence, state openness, willingness to create, capability to create - divergent thinking, and convergent thinking.

5.2. Apparatus and materials

5.2.1. Setting

The experiments were held in an indoor lab. A table and a chair were set for participants to complete the questionnaires on an iPad Air 4. An Epson EB 2255 U projector projected the video showing the WM exercise on a white wall. The voice instruction was played by the audio function of the same device. We marked a red cross on the floor in the middle of the room. Participants were required to step on the mark to do an on-spot walking exercise. Participants in the LKM group had a chair to sit on. Instruction was played by an iPad in the

audio-guided group.

For both robot-guided WM and LKM, a NAO robot was put on a table, in a standing or sitting position respectively. In the work section of the experimenter, a computer connected to the Internet through a router controlled the robot (Fig. 2).

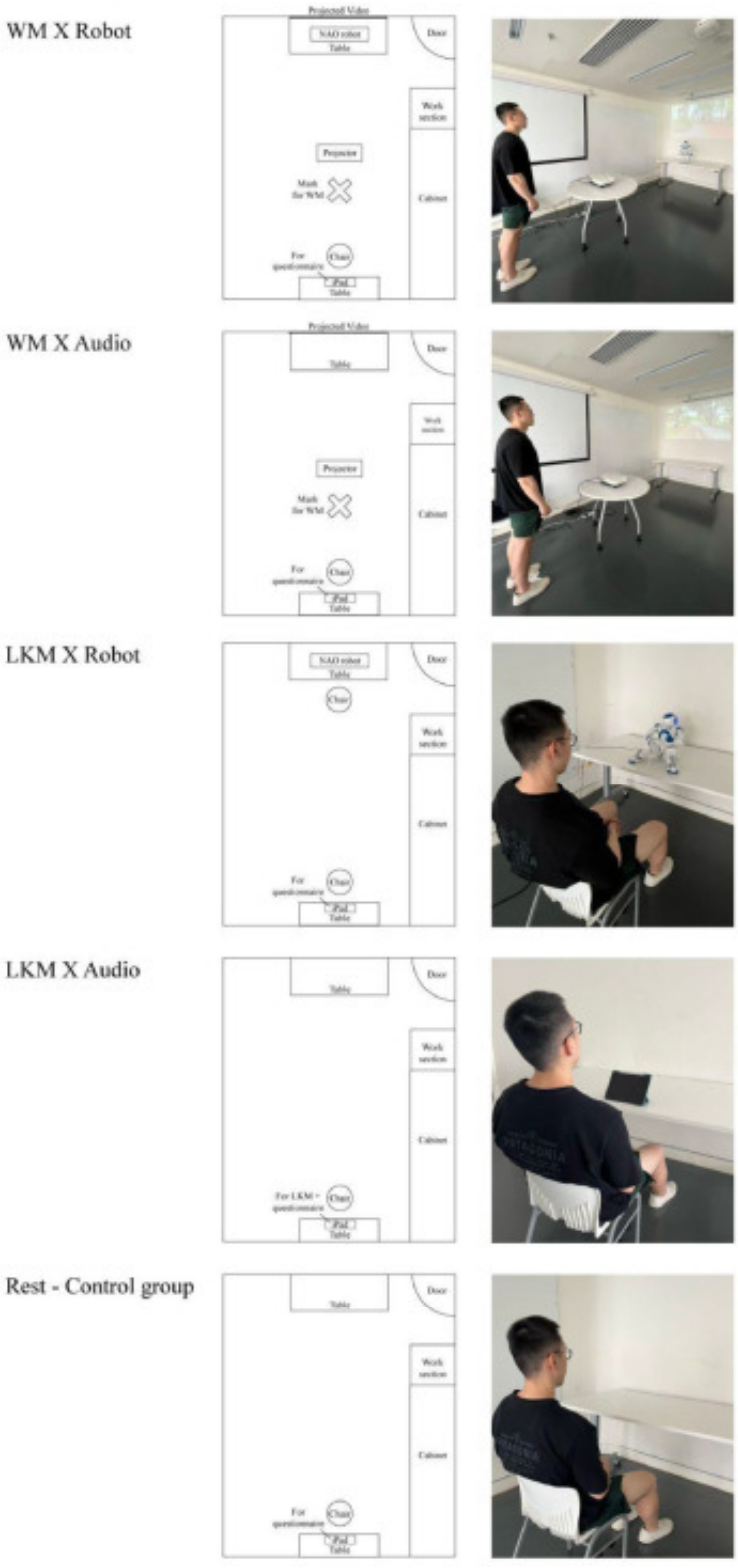

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Fig. 2. Setting.

5.2.2. Robot

A NAO V5 equipped with ZoraBots software was used for all robot-guided interventions. NAO is a humanoid technological interface designed for childcare, eldercare, education, hospitality, and retail. Previous research has shown its effectiveness as a trainer.
Pino et al. (2019) programmed NAO with a memory-training program protocol, resulting in an increase in visual gaze and a reduction in depressive symptoms. Rossi et al. (2022) used NAO for emotional support while children waited for emergency-room consultation: Compared to playing with a nurse or waiting with parents, interacting with NAO was more effective in decreasing stress and improving emotional perceptions in a stressful environment.

NAO is 12.2 inches tall, with microphones and cameras as sensors to collect and transmit data for communication. It is humanoid in appearance with a head, two eyes, arms, hands, legs, and feet. Its appearance and tone of voice are gender-neutral, avoiding bias caused by perception. The ZoraBots solution furnishes easier control of the robot. Pre-programmed activities and actions, such as waving, sitting, and standing, allow for a more manageable action design. The robot is proficient in speaking English and Mandarin. To design the WM and LKM guided by robots, the software package Choregraphe was used as a graphical environment for programming. We inputted text for speech and designed the action to control the robot for a particular intervention.

5.2.3. Scripts, interaction and video

According to the recommendation of the U.S. Department of Health and Human Services (2008) for the smallest length of an activity that yields health benefits, all the intervention scripts were designed to introduce a 10 min exercise.

The scripts for robot and audio-guided meditation were in a similar

format, except that the robot introduced itself before the intervention and talked during the physical actions. Participants were required to follow the audio or robot-guided instruction, but there was no conversation between the two parties. Between each sentence, there was time for the participants to take a breath, imagine a particular scene, or walk as required. NAO's built-in speech function was used to read out the script aloud in English, which is one of the official and widely understood languages in Hong Kong. For the audio-guided interventions, scripts were converted into natural-sounding speech (female voice), using the Google Cloud Text-to-Speech tool. All scripts were presented in English.

The script for LKM was adapted from Bendit-Shtull's (2017) version, which showed positive effects on state compassion and pleasantness after completing the exercise Physical Activity Guidelines Advisory Committee (2008). The original script is 15 min long, which we changed into 10 min (U.S. Department of Health and Human Services, 2008). We aimed at a focused practice of cultivating positive emotion and instructed the participants to think of a particular person or group so as to spread love and kindness to them.

The script for the WM was adapted from Bendit-Shtull's (2017) mindfulness induction as well as from Nisbet et al. (2019) mindfulness walking exercise. The purpose of this exercise was to keep participants walking while mind-wandering, which facilitates state openness afterwards. The script was designed to guide participants to focus on walking, then explore the surroundings, and finally spread their attention to whatever they preferred.

Since it was an indoor exercise, a video of a park was displayed during the intervention to give a sense of ‘being in the park.’ The video was an edit of Walking in Beacon Hill Park from Virtual Videos

Channel (2019), offering a first-person perspective on natural park scenery with related sound. For the robot-guided WM group, the NAO robot stood in front of the screen while the video played in the background.

For all the intervention groups, gentle instrumental background music was added, played by the robot, iPad, or the audio function of the projector. The song *Hidden Within* (Cross, 2016) was adapted from Freeplay music, "Revealing Emotions," Acoustic Moods, Vol. 9.

5.3. Procedure

Each session took around 35 min to complete. Upon arrival, the experimenter welcomed participants, introduced the experiment, and answered questions. Participants uninformed of the purpose of the study signed the consent form and were debriefed after the experiment. As a baseline before treatment, participants completed the first set of questionnaires (QS1) related to valence, state openness, and creativity (i.e., willingness to create and two tests for capability to create).

Next, participants were assigned to 10 min of intervention, either WM or LKM. For the WM group, participants started an on-spot walking exercise while watching a video. An audio instructor or a physically present NAO guided the exercise. For the LKM group, participants practiced a 10 min meditation that aimed to induce a feeling of love and kindness. The meditation content was presented by an audio instructor or a NAO robot sitting on a table. No treatment was assigned to the participants in the control group: They sat still and took a rest for 10 min.

After the intervention, participants completed the second set of questionnaire items (QS2), which included the same constructs and

items as QS1. The questionnaire ended with items for checking the manipulation and for demographics.

Coupons from a coffee shop or a supermarket were offered as a reward after completing the experiment. To attract more participants, we prepared a lucky draw. Winners received a Hanson's Professor Einstein™ robot as a reward.

5.4. Measurement

The part of our model that we tested (Fig. 1) can be divided into two: First, we investigated the effects of different invention treatments (i.e., robot or audio-guided WM, LKM, and the control group resting). We targeted to find group differences in mental states: positive valence *(Val1, Val2)* and state openness (*SOpen1, SOpen2*). Second, we addressed how mental states affect creativity (*Will1, Will2, AUT1, AUT2, RAT1, RAT2*). Additionally, we tested the correlation between different attributes (e.g., positive valence and state openness).

The questionnaire had 10 measurement scales, including before and after treatment: valence *(Val1, Val2)*, state openness *(SOpen1, SOpen2)*, willingness to create *(Will1, Will2)*, capability to create: divergent thinking *(AUT1, AUT2)* and convergent thinking *(RAT1, RAT2)*. At the end of the questionnaire, manipulation check, trait openness, and demographic information were collected as control factors. Valence, state openness, and willingness to create were designed as Likert-type statements with a 6-point rating scale (1 = strongly disagree, 6 = strongly agree). The counter-indicative items were re-coded into new variables. Table 1 shows the description of each scale.

Table 1. Measurements.

Index	Sub-aspects	Description	Number of items	Abbreviation & value
Before intervention (1), After intervention (2)				
1	Valence	Positive or negative dimension of emotion	8	*Val1_1…8* = [1,6] *Val2_1…8* = [1,6]
2	State openness	Momentary expression of openness to new experiences and information	8	*SOpen1_1…8* = [1,6] *SOpen2_1…8* = [1,6]
3	Willingness to create	Readiness to participate in creative activities	4	*Will1_1…4* = [1,6] *Will2_1…4* = [1,6]
4 / 5	AUT	Level of divergent thinking	3 (6 boxes each)	*AUT1_1_1…* *AUT1_3_6* = [0,1] *AUT2_1_1…* *AUT1_3_6* = [0,1]
5 / 4	RAT	Level of convergent thinking	10	*RAT1_1…RAT1_10* = 1 [0,1] *RAT2_1…RAT1_10* = 1 [0,1]
Control factors				
6	Manipulation Check	Did the participant complete the intervention correctly?	2	*Man_Walk_1…* *2* = [1,6] *Man_Med_1…2* = [1,6] *Man_Rest_1…3* = [1,6]
7	Trait openness	Level of trait openness	4	*TOpen_1…4* = [1,6]
8	Gender	–	1	*Gender* = [Male,

				Female, Other]
9	Age	–	1	*Age* = [18, 34]
10	Highest education	–	1	*Edu* = [Primary school or below, Secondary school, Post-secondary school / Associate degree / Diploma, University or above]
11	Region	–	1	*Region* = [Hong Kong, Mainland China, Other]

We first checked participants for acquiescence bias and identified those who gave the same responses for all items on a scale. We found four cases - participant #27 (*Val1, SOpen1*), #98 (*Will1*) and #132 (*Val1*). In the analyses, these participants were disregarded for scales where they showed acquiescence bias but were maintained for all other scales. We performed two rounds of reliability analysis with a Principal Component Analysis (PCA) in between, to examine the factor structure of the items. Decisions on items including in or removing from the following *t*-test or *F*-test were based on statistics and an understanding of outcomes. Validation details can be found in the Technical Report (see Supplementary materials).

Valence was measured before and after the intervention. The scale was adopted from Duan et al. (2021) on self-discourse to a robot. We were interested in a shift in emotional tendency, rather than some specific emotion. During our pilot, however, we used 'emotion' as our scale but did not balance the number of positive (2) and negative items (10). The Valence scale, therefore, was revised such that the reliability of the scale improved (Cronbach's α = 0.86) (see Supplementary materials).

State openness in the pilot study was adopted from Svedholm-Häkkinen and Lindeman's (2018) shortened version of Actively Open-minded Thinking (AOT). The central concept is to query people's ability to avoid 'myside bias' (i.e., but one single opinion) and see things from different perspectives. However, 5 out of 8 items on the open-mindedness scale needed to be removed after the reliability test (see Supplementary materials). In the literature, open-mindedness is usually considered a trait, but we were interested in the difference before and after the intervention; that is, openness as a state. The original scale was redesigned to include statements with instant awareness of the moment, but not those related to personality and habit (Cronbach's $\alpha = 0.75$). For example, 'My blood boils over whenever a person stubbornly refuses to admit he is wrong' was changed into 'I noticed my emotions.'

Willingness to create was inspired by Dewett's (2006) preparedness to take risks and Ogbeibu et al. (2021) Team Creativity Willingness Scale. We used the basic ideas of those scales to probe the participants' motivation to engage in creative behaviors. The pilot study featured 5 items but to improve the readability of the scale, we shortened the description and created a new scale with four items, including two counter-indicative items (Cronbach's $\alpha = 0.73$). For instance, 'I am willing to think of creative ideas despite the possibility of potential failure to try out' was changed to 'I am willing to participate in creativity-related activities.'

Capability to create included two measurements to test the ability of divergent thinking *(AUT1, AUT2)* and convergent thinking *(RAT1, RAT2)*. In both tests, participants were asked to answer as many questions as possible within 4 min time before and after the intervention. The Alternative Uses Task (AUT) was adopted from the Mind Garden (2023) (https://www.mindgarden.com/67-alternate-uses#horizontalTab1), which was originally designed by

Wilson et al. (1954). It is a test for measuring one's capability of divergent thinking, which is related to originality, fluency, flexibility, and elaboration. Before and after the intervention, participants were asked to consider three common objects. Each of those objects (e.g., a broom) has a common use. Participants were to list as many as six other uses for which the objects or part of the object could serve (e.g., to bang at the ceiling, to dry clothes, to make a scarecrow). The Remote Associate Test (RAT) was adopted from Wu and Chen's (2017) Chinese Remote Associate Test, measuring one's capability of convergent thinking. The design was based on the creativity association theory, stating that creative people are more able to tie interdependent elements into novel outcomes. There were 10 items for each section, each item comprising of three "stimulus words". For example, 療 ("treatment"), 防 ("prevent") and 統 ("unite"). Participants were asked to come up with a target word 治 ("heal") that could combine all three stimuli to create three two-character words - 治療 ("cure"), 防治 ("control"), and 統治 ("dominant"). To avoid confusion, only target words that had the same pronunciation for all stimuli were chosen. Twenty items with the highest pass rate were evenly distributed over two parts of the test before and after the intervention. Lastly, we performed outlier analysis before and after intervention and identified 14 cases. Consequently, we will use two data sets: with (N = 142) and without outliers (n = 128). Details can be found in the Technical Report (see Supplementary materials).

5.5. Coding

To make data comparable, we coded the results of AUT and RAT by training coders with a manual, designating the units of analysis (Syed and Nelson, 2015). For AUT, two coders marked all responses either as acceptable (1 point) or unacceptable (0 points). Coders

were required to code the responses separately and reconcile differences via consensus afterwards. In the end, all scores were added together and named *AUT1* (before intervention) and *AUT2* (after intervention). Cohen's Kappa Coefficient (1960) was used to measure the inter-coder-reliability (κ = 0.79). For RAT, one coder checked the answers with the target words from Wu and Chen's (2017) research. Correct answers received 1 point and incorrect words received 0. After coding all the answers, scores of the 10 items were added, named *RAT1* (before intervention) and *RAT2* (after intervention).

6. Results

6.1. Demographic composition

All of the 142 participants completed the experiment. Table 2 shows the demographic distribution of the two datasets (*N* = 142, *n* = 128).

Table 2. Demographic composition of experimental groups.

Treatment & media	**WM (*N* = 57)**		**LKM (*N* = 56)**		**Rest (*N* = 29)**	**Ou incl (*N* =**
	Robot (*N* = 29)	**Audio (*N* = 28)**	**Robot (*N* = 28)**	**Audio (*N* = 28)**	*/*	
Gender						
Male	12	17	12	8	13	62
Female	17	11	16	20	15	79
Others	0	0	0	0	1	1
The highest educational level						
Primary school or below						

Secondary school Post-secondary school/ Associate degree/ Diploma University or above	0 7 4 18	0 8 8 12	0 1 1 25	0 5 2 21	0 6 8 15	0 27 24 91
Age 20 or below 21 - 25 26 - 30 Above 30	 8 9 7 5	 15 10 2 1	 6 10 7 5	 9 9 7 3	 17 10 1 1	 55 48 24 15
Region Hong Kong Mainland China Others	 19 9 1	 21 7 0	 13 15 0	 22 5 1	 17 12 0	 92 48 2
Treatment & media	WM (n = 52)		LKM (n = 48)		Rest (n = 28)	Out excl (n =
	Robot (n = 24)	Audio (n = 28)	Robot (n = 25)	Audio (n = 23)	/	
Gender Male Female Others	 10 14 0	 17 11 0	 11 14 0	 7 16 0	 13 14 1	 58 69 1
The highest educational level Primary school or below Secondary school Post-	 0 6 4	 0 8 8	 0 1 1	 0 5 0	 0 6 8	 0 26 21

secondary school/ Associate degree/ Diploma University or above	14	12	23	18	14	81
Age 20 or below 21 - 25 26 - 30 Above 30	 7 7 6 4	 15 10 2 1	 4 10 6 5	 6 7 7 3	 17 9 1 1	 49 43 22 14
Region Hong Kong Mainland China Others	 15 8 1	 21 7 0	 12 13 0	 17 5 1	 16 12 0	 81 45 2

6.2. Baseline knowledge

In Table 3, the average scores and standard deviations for all factors are provided for the five measures. No significant differences were found in the baseline values (t_0) of *MVal1, MSOpen1, MWilll1, MAUT1,* and *MRAT1* in *media, treatment,* and *rest* (the control group), meaning that all groups across factors showed comparable baseline levels of valence, state openness, willingness, and capability to create. Thus, before treatment, participants were in a similar mental state and with comparable levels of creativity.

Table 3. Mental state and everyday creativity for all groups before intervention (*N* = 142 and *n* = 128).

Group	***n***	***MVal1*** **(M, *SD*)**	***MSOpen*****1** **(M, *SD*)**	***MWill1*** **(M, *SD*)**	***AUT1*** **(M, *SD*)**	***RAT1*** **(M, *SD*)**
N = 142						
Treatment		4.54		4.69	4.47	4.88

- WM	57	0.68	4.43 0.77	0.81	2.65	2.45
Treatment - LKM	55	4.50 0.86	4.40 0.78	4.79 0.77	3.98 2.46	4.64 2.05
Media - robot	57	4.50 0.71	4.38 0.77	4.74 0.77	4.32 2.61	4.72 2.11
Media - audio	56	4.54 0.84	4.45 0.77	4.74 0.82	4.14 2.53	4.80 2.41
Rest (Control)	29	4.71 0.63	4.76 0.65	4.75 0.81	3.93 2.20	3.72 1.98
n = 128						
Treatment - WM	52	4.61 0.59	4.45 0.68	4.76 0.79	4.53 2.69	4.94 2.47
Treatment - LKM	48	4.65 0.77	4.48 0.76	4.92 0.68	4.00 2.48	4.44 2.02
Media - robot	49	4.61 0.59	4.43 0.64	4.85 0.74	4.22 2.62	4.78 2.12
Media - audio	51	4.64 0.76	4.50 0.78	4.84 0.75	4.14 2.56	4.63 2.42
Rest (Control)	28	4.78 0.55	4.80 0.62	4.75 0.83	3.93 2.24	3.75 2.01

6.3. Effects of media vs. treatment vs. rest on experience (difference scores)

To analyze the effects of treatment, we calculated the difference scores of all scales by subtracting the pretest score from the posttest score. To make the scores of different scales comparable, we translated the difference scores into *z*-scores (i.e. *zD_MVal, zD_MSOpen, zD_MWill, zD_MAUT,* and *zD_MRAT)*. Then we ran a multivariate analysis of covariance (MANCOVA) of *treatment* (3) × *media* (3) on *zD_MVal, zD_MSOpen, zD_MWill, zD_MAUT* and *zD_MRAT* with gender, region, age, and education as covariates (*N* = 142). In this analysis, *rest* as the control group was encoded as

the third *media* and *treatment* condition.

The only significant effect found was the interaction of *treatment* × *media* on *zD_MVal* ($F_{(5134)}$ = 5.69, p = .019, η_p^2 = 0.042). Two-tailed independent samples t-tests indicated that the effects were significant between WM × Audio (M = –0.089; SD =0.83) and LKM × Audio (M = 0.38; SD = 0.85), t = –2.093, p = .041, as well as between LKM × Audio (M = 0.38; SD = 0.85) and Rest (M = –0.27; SD = 0.76), t = 3.02, p = .004. However, there were five conditions in the analysis (i.e. WM × Robot, LKM × Robot, WM × Audio, LKM × Audio and Rest), so the rejection area α should be corrected, according to Bonferroni (0.05 / 10 = 0.005). Hence, only LKM × Audio exerted significant effects on *zD_MVal* compared to the control group *rest*, indicating that participants who practiced audio-guided LKM significantly improved valence (i.e. they became more positive).

We ran the analysis again with n = 128. However, the effect of *treatment* × *media* on *zD_MVal* disappeared whereas the effect of *media* on *zD_MSOpen* ($F_{(3125)}$ = 4.087, p = .046, η_p^2 = 0.034) became significant. To scrutinize the effects of *media*, we did three two-tailed independent t-tests of *media* (*Robot - Audio, Robot - Rest* and *Audio - Rest*) on *zD_MSOpen*. With Bonferroni-corrected alpha (0.05 / 3 = 0.0167), the change of state openness of participants in the audio-guided group (M = 0.35; SD =0.79) was significantly higher than those in the control group (M = –0.41; SD =0.86), t = 3.96, p = .00. Yet, the differences between *Robot* and the other two groups (*Robot - Audio:* t = –2.20, p = .030; *Robot - Rest:* t = 1.290, p = .20) were not significant.

Moreover, in both datasets (N = 142 and n = 128), gender, age, region, and education did not significantly correlate with *zD_MWill, zD_MAUT, zD_MRAT, zD_MSOpen*, and *zD_MVal*. Covariates did not

affect the change in mental state and creativity.

6.4. Effects of media vs. treatment vs. rest on the final state (after intervention)

To analyze the effects of *media* and *treatment* on state valence and state openness, we replicated the analyses in Section 6.3 with the *z*-scores of post measurements (*zM_Val2, zM_SOpen2, zM_Will2, zM_AUT2,* and *zM_RAT2*). With $N = 142$ and $n = 128$, *media* (Robot, Audio and the control group) had a significant effect on *zM_SOpen2* ($N = 142$: $F_{(3142)} = 4.39$, $p = .038$, $\eta_p^2 = 0.032$; $n = 128$: $F_{(3128)} = 6.17$, $p = .014$, $\eta_p^2 = 0.049$). Then, we ran three two-tailed independent *t*-tests on *zM_SOpen2* with the two datasets respectively, but no significant effects occurred. Neither *media* nor *treatment* had a significant effect on the final state openness (see Supplementary materials).

6.5. Mediation-moderation analysis

The hypothesized mediation models with and without moderation effect were tested with PROCESS in SPSS 27, using mean-centered (*z*-score) variables, with $N = 142$ and $n = 128$ separately. Point estimates for effects were assumed significant if at least one 95% confidence interval (CI) did not straddle zero, as indicated by 5000 boot-strapped samples (Hayes, 2018). Results are presented next.

6.5.1. Treatment influences creativity through valence and state openness

To analyze valence (*zM_Val2*) and state openness (*zM_SOpen2*) as mediators of the relationship between treatment and creativity (*zM_Will2, zM_AUT2,* and *zM_RAT2*), we followed the PROCESS procedures designed by Hayes and Preacher (2013) and

Hayes (2018). Since *treatment* was categorical (WM = 1, Rest = 2, LKM = 3), we used multi-categorical multiple mediation analyses (Hayes's Model 4) to simultaneously probe the individual effects of *treatment* on creativity through mental state (*zM_Val2* and *zM_SOpen2*). Therefore, *zM_Val2* and *zM_SOpen2* were entered as mediators and two dummy-coded variables (X1 and X2) were created for the multiple mediation analyses. Specifically, X1: Rest vs. WM & LKM; X2: WM vs. LKM. PROCESS allows for one dependent variable, but creativity had three subscales. Therefore, we replicated the analysis with three dependent variables, respectively. Fig. 3 shows the mediation analysis for $N = 142$; between brackets are the significant results for $n = 128$.

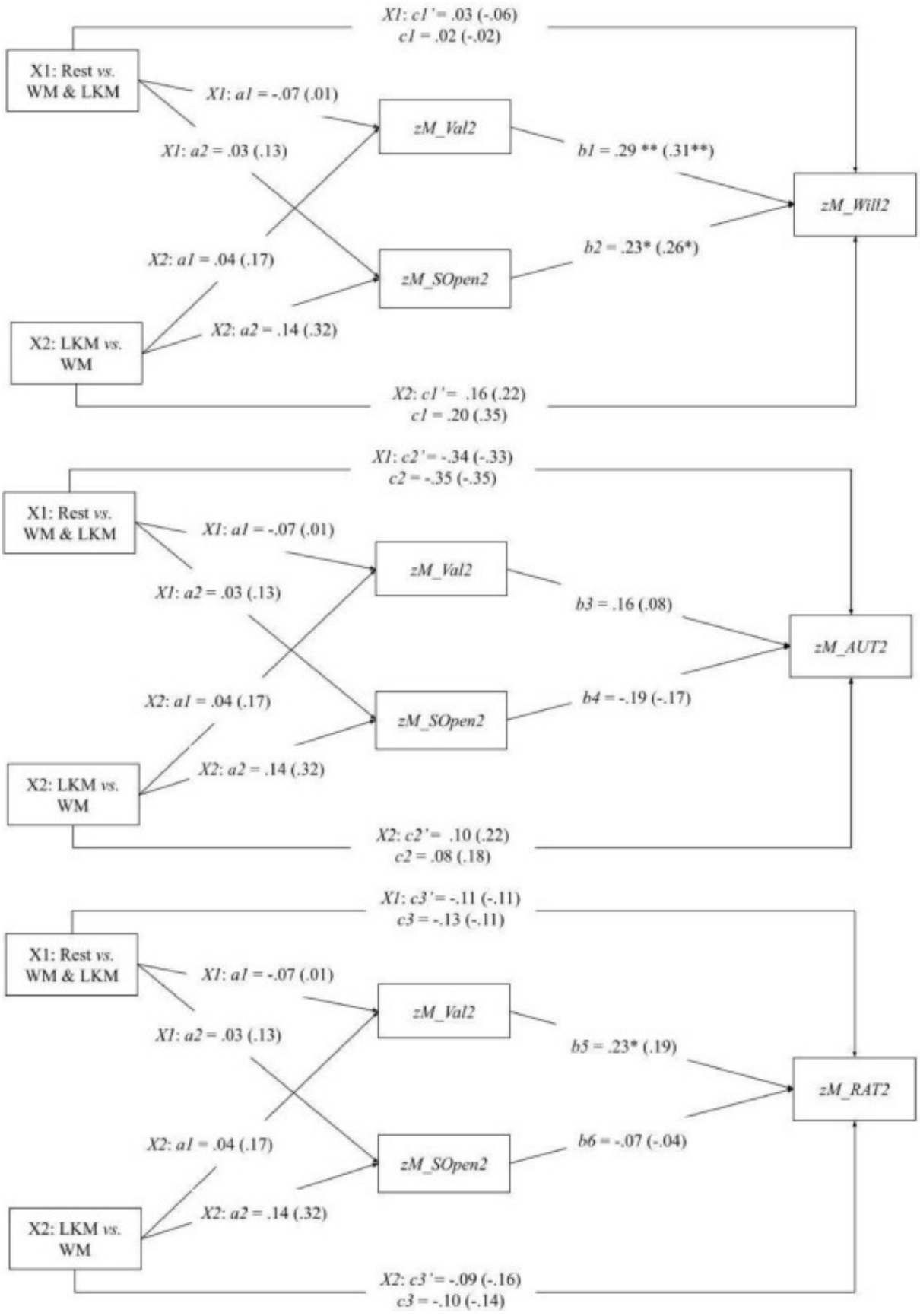

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Fig. 3. Relative indirect effects of *treatment* on creativity through positive valence and

state openness with estimated coefficients (bootstrap) for $N = 142$: *$p < .05$; **$p < .01$. Significant paths for $n = 128$ between brackets.

To test H1 and H2, postulating that the treatments resulted in higher levels of *zM_Val2* and *zM_SOpen2*, the direct effects of X1 and X2 *treatment* contrasts on mental state components were explored. In Fig. 3, variable *a* represents the direct effect of a multi-categorical antecedent variable on the mediators in a model (Hayes, 2018). As indicated in Fig. 3., X1 contrast (Rest vs. WM and LKM) and X2 contrast (LKM vs. WM) did not exert significant direct effects on *zM_Val2* (X1 ($N = 142$): $b = -0.07$, $t = -0.30$, $p = .77$; X2 ($N = 142$): $b = 0.04$, $t = 0.19$, $p = .85$; X1 ($n = 128$): $b = 0.01$, $t = 0.06$, $p = .95$; X2 ($n = 128$): $b = 0.17$, $t = 0.91$, $p = .37$).

X1 and X2 contrast also did not have significant direct effects on *zM_SOpen2* (X1 ($N = 142$): $b = 0.03$, $t = 0.12$, $p = 0.90$; X2 ($N = 142$): $b = 0.14$, $t = 0.72$, $p = .47$; X1 ($n = 128$): $b = 0.13$, $t = 0.58$, $p = .57$; X2 ($n = 128$): $b = 0.32$, $t = 0.1.71$, $p = .09$). WM and LKM had no significant effect on positive valence and state openness, even compared to *rest*. Therefore, H1 and H2 were rejected. *Treatment* did not have a significant indirect impact on creativity through the mental state components (i.e., *zM_Val2* and *zM_SOpen2*). In our mediation analyses, *c'* quantified the direct effect of *treatment* contrasts on *creativity* without passing through the mediators (i.e., *zM_Val2* and *zM_SOpen2*). As Fig. 3. shows, the relative direct effects of *treatment* contrasts on *creativity* were not statistically significant. Thus, having treatment or not (X1: Rest vs. WM & LKM) and types of *treatment* (X2: LKM vs. WM) did not exert direct or indirect effects (through *zM_Val2* and *zM_SOpen2*) on *creativity*.

Partial support was found for H4 and H5 that mental state components (i.e., *zM_Val2* and *zM_SOpen2*) had a direct influence on creativity, in terms of willingness and convergent thinking. In

Fig. 3, variable *b* indicates the direct effects of a mediator on dependent variables. Both *zM_Val2* and *zM_SOpen2* rendered a significantly positive effect on *zM_Will2*, with *N* = 142 (*zM_Val2: b* = 0.29, *t* = 3.02, *p* = .00; *zM_SOpen2: b* = 0.23, *t* = 2.43, *p* = .02) as well as *n* = 128 (*zM_Val2: b* = 0.31, *t* = 3.18, *p* = .00; *zM_SOpen2: b* = 0.26, *t* = 0.09, *p* = .01). Effects remained insignificant for *zM_AUT2* (*zM_Val2* (*N* = 142): *b* = 0.16, *t* = 1.50, *p* = .14; *zM_SOpen2* (*N* = 142): *b* = −0.19, *t* = −1.83, *p* = .07; *zM_Val2* (*n* = 128): *b* = 0.08, *t* = 0.71, *p* = .48; *zM_SOpen2* (*n* = 128): *b* = −0.17, *t* = −1.51, *p* = .13)).

Regarding convergent thinking (*zM_RAT2*), only for *N* = 142, the relation between *zM_Val2* and *zM_RAT2* was significant (*b* = 0.23, *t* = 2.13, *p* = .03) but disappeared with *n* = 128 (*b* = 0.19, *t* = 1.65, *p* = .10) maybe due to a lack of power (see Supplementary materials).

It seems, then, that positive valence and state openness contributed to the willingness to create (i.e., H4a and H5a accepted), but not to divergent thinking (i.e., H4b and H5b rejected). Regarding convergent thinking, only positive valence influenced the performance (i.e., H4c accepted and H5c rejected).

6.5.2. Media moderated treatment on valence and state openness

We used PROCESS Model 7 (Hayes, 2018) to analyze our hypothesis that *media* (Robot and Audio) moderated the relationship between the predictor *treatment* and the mediators (*zM_Val2* and *zM_SOpen2*). We excluded the control group because no moderation effect could be expected there. Hence, *treatment* contained two categories (Robot and Audio) and PROCESS analysis for *N* = 142 and *n* = 128 (between brackets) showed the results depicted in Fig. 4.

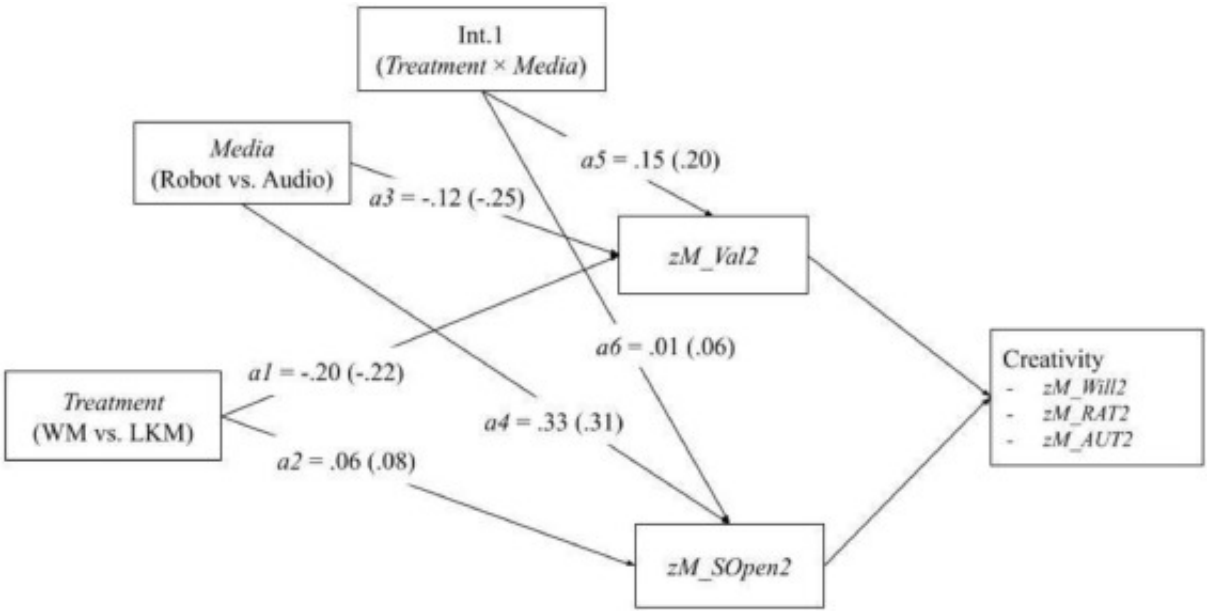

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Fig. 4. Effect of *media* on the relationship between *treatment* and mental state components (positive valence and state openness) with estimated coefficients (bootstrap) for $N = 142$: *$p < .05$; **$p < .01$. Significant paths for $n = 128$ between brackets.

As shown in Fig. 4., the *treatment* × *media* interaction on *zM_Val2* ($N = 142$:

$b = 0.15$, $t = 0.77$, $p = .44$; $n = 128$: $b = 0.20$, $t = 1.08$, $p = .28$) and *zM_SOpen2* ($N = 142$:

$b = 0.01$, $t = 0.042$, $p = .97$; $N = 128$: $b = 0.06$, $t = 0.33$, $p = .74$) was not significant. This suggested that *media* did not have moderation effects on the relationship between *treatment* and *zM_Val2*, nor between treatment and *zM_SOpen*2. Therefore, H6a and H6b were rejected.

6.5.3. Treatment influenced creativity through valence and openness (difference scores)

To investigate the effect of *treatment* from the perspective of mental state and creativity change, we replicated the mediation analyses

with the discrepancy data. Therefore, *zD_MVal* and *zD_MSOpen* served as mediators and *zD_MWill, zD_MAUT,* and *zD_MRAT* as dependent variables.

In $N = 142$, *treatment* significantly predicted *zD_MSOpen* ($b = -0.48$, $t = -2.10$, $p = .04$) under X1 contrast but not anymore in $n = 128$. In both datasets, *zD_MSOpen* did not significantly predict *zD_MAUT* ($N = 142$: $b = -0.12$, $t = -1.28$, $p = .20$; $n = 128$: $b = -0.18$, $t = -1.78$, $p = .08$), *zD_MRAT* ($N = 142$: $b = -0.01$, $t = -0.09$, $p = .93$; $n = 128$: $b = -0.02$, $t = -0.20$, $p = .85$), and *zD_MWill* ($N = 142$: $b = 0.03$, $t = 0.41$, $p = .68$; $n = 128$: $b = 0.05$, $t = 0.53$, $p = .59$).

Whether using $N = 142$ or $n = 128$, *treatment* did not significantly explain *zD_MVal*, neither under X1 ($N = 142$: $b = -0.32$, $t = -1.40$, $p = .16$; $n = 128$: $b = -0.22$, $t = -0.96$, $p = .34$) nor under X2 contrast ($N = 142$: $b = 0.04$, $t = 0.20$, $p = .84$; $n = 128$: $b = 0.07$, $t = 0.38$, $p = .71$). Also, *zD_MVal* could not predict creativity in terms of *zD_MAUT, zD_MRAT*, and *zD_MWill*. In terms of difference scores, H1, H4, and H5 were rejected. However, H2 was accepted for $N = 142$ (Fig. 5).

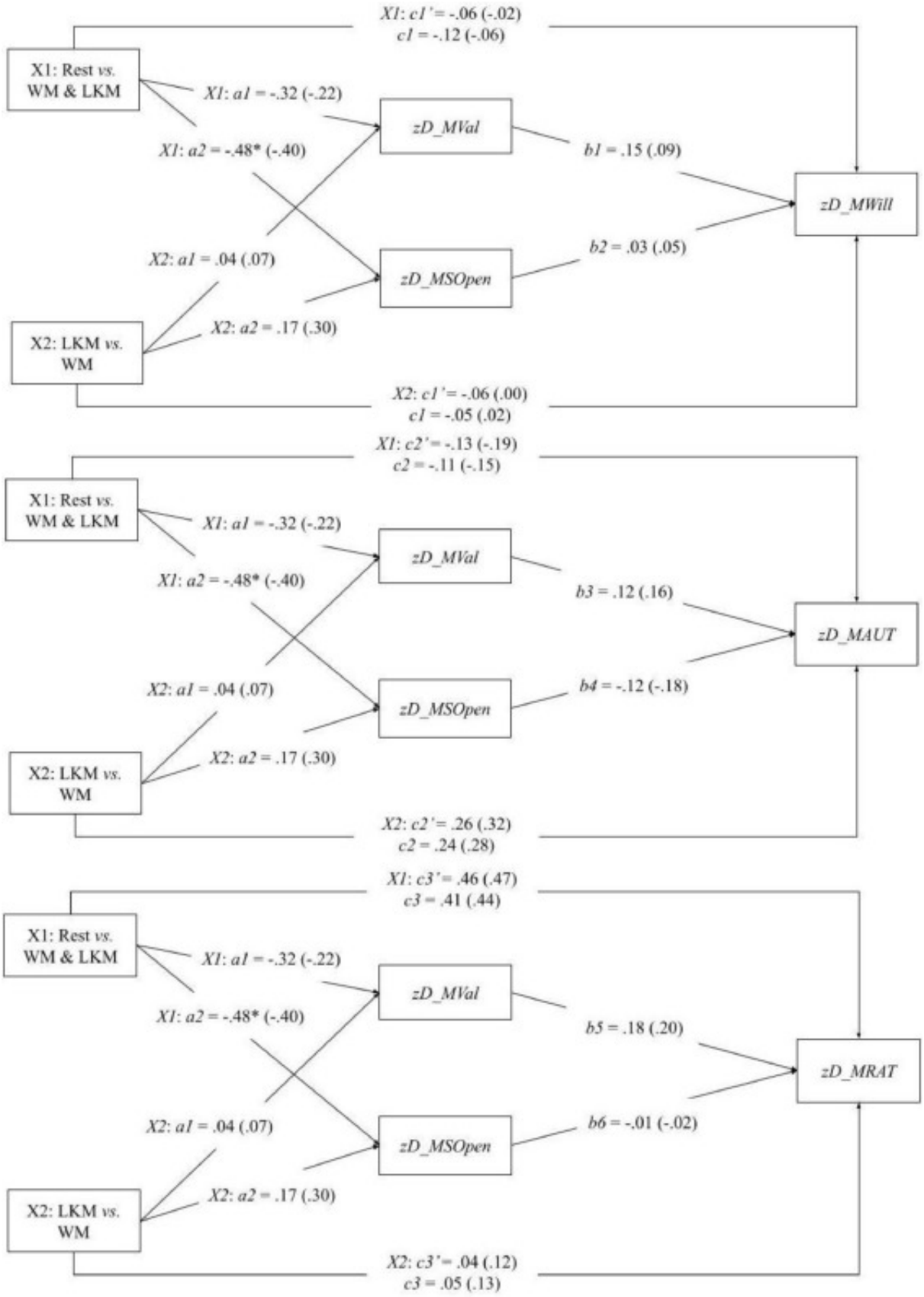

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Fig. 5. Effects of *treatment* on *creativity* through positive valence and state openness with estimated coefficients (bootstrap), $N = 142$: *$p < .05$; **$p < .01$. Significant paths for

n = 128 between brackets.

6.5.4. Media moderated treatment on valence and state openness (difference scores)

Our next set of moderation analyses concerned *media*, using the difference scores with *zD_MVal* and *zD_MSOpen* as parallel mediators and *media* as the moderator. Results indicated that *treatment* and the interaction of *treatment* × *media* significantly predicted *zD_MVal* with *N* = 142 (*treatment: b* = –7.2, *t* = –1.66, *p* = .10; *treatment* × *media: b* = 0.44, *t* = 2.22, *p* = .03) but not with *n* = 128 (*treatment: b* = –0.50, *t* = –1.12, *p* = .27; *treatment* × *media: b* = 0.33, *t* = 1.60, *p* = .11). Therefore, we could not accept H6a for *n* = 128. Regarding *N* = 142, effects of *treatment* on *zD_MVal* for different *media* (robot vs. audio) were not significant (robot: *b* = –0.20, *t* = –1.45, *p* = .15; audio: *b* = 0.23, *t* = 1.70, *p* = .09). *Media* did not moderate the effect of *treatment* on *zD_MVal* with *N* = 142. Therefore, we rejected H6a for *N* = 142, which assumed that robots would perform better than audio. Taken together, *treatment* × *media* did not influence *zD_MSOpen* with *N* = 142 (*b* = 0.13, *t* = 0.66, *p* = .51) nor with *n* = 128 (*b* = 0.15, *t* = 0.77, *p* = .45). Additionally, *treatment* could not predict *zD_MSOpen* (*N* = 142: *b* = –0.10, *t* = –0.34, *p* = .74; *n* = 128: *b* = –0.07, *t* = –0.22, *p* = .83). Therefore, we concluded that H6a and H6b were not validated (Fig. 6).

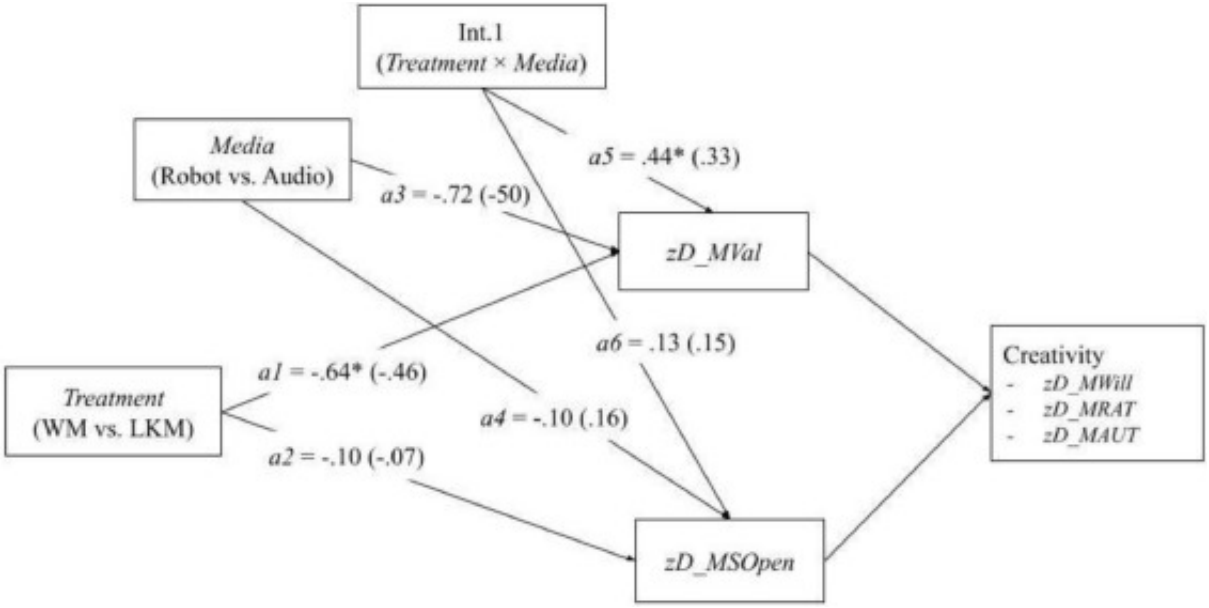

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Fig. 6. Effects of *media* on the relationship between *treatment* and mental state components (positive valence and state openness) with estimated coefficients (bootstrap) for $N = 142$: *$p < .05$; **$p < .01$. Significant paths for $n = 128$ between brackets.

6.6. Correlation analyses

We calculated Pearson correlations between valence (*M_Val1, M_Val2*) and state openness (*M_SOpen1, M_SOpen2*) with two datasets separately with $\alpha = 0.05$. Significant positive correlations were observed between *M_Val1* and *M_SOpen1* ($N = 142$: $r = 0.53$, $p < .000$; $n = 128$: $r = 0.53$, $p < .000$) as well as *M_Val2* and *M_SOpen2* ($N = 142$: $r = 0.60$, $p < .000$; $n = 128$: $r = 0.53$, $p < .000$). The correlation coefficient between valence and state openness was larger than 0.50, suggesting a large effect size (Cohen, 1995). When valence became more positive, the level of state openness tended to increase, corroborating H3.

6.7. Summary of results

1

From baseline analyses, we found:
a

Different treatment effects across groups could not come from participants' original mental state and creativity, owing to randomized distribution of mental state and creativity components across *treatment* vs. *media* vs. *rest*.

2

MANOVA with post-test scores and difference scores suggested:
a

With $N = 142$, those who did LKM with audio guidance showed a significantly bigger change in positive valence (*zD_MVal*) than those in the control group by 0.65. Rerunning the same with $n = 128$ did not yield significant results. Thus, LKM is only for those who suffer the most (Duan et al., 2021).

b

With $n = 128$, audio-guided meditation improved state openness (*zD_MSOpen*) compared to the control group.

c

After the intervention, we found no significant differences in mental state or creativity across *treatment, media,* and *rest*.

3

From regression analysis with the post-test scores, we found:
a

With both datasets, *treatment* did not exert significant effects on

valence and state openness; *media* did not play a moderating role in the relationship between *treatment* and mental state.

b

With both datasets, mental state had a positive effect on the willingness to create, but not on divergent thinking. With $N = 142$, which included participants with low positive valence, we found a positive effect of valence on convergent thinking. Again, only for those who suffer the most (Duan et al., 2021).

4

Regression analysis with the difference scores indicated:
a

With $N = 142$, those who received treatment became more open with an average score of 0.48 increase compared to the control group. Duan et al. (2021) was confirmed once more.

b

No other direct effect, mediation effect, or moderated effect was significant.

7. Discussion

Social robots are increasingly explored for their potential in mental healthcare (Lal and Adair, 2014; Robinson et al., 2019), yet few researchers focused on young adults. Guided meditation is one of the most popular approaches for increasing mental health, and many meditation approaches contain elements to stimulate creativity (e.g., Baas et al. 2014: positive emotion, less stress). Pursuing daily creativity is thought to bring psychological benefits (Goyal et al., 2014). Therefore, we chose LKM and WM as treatments for the

maintenance of mental health and the reduction of negative mood in the long term. We explored and evaluated the influence of robot and audio-guided meditation on willingness and capability to create by increasing positive valence and state openness. Compared to a group in *rest*, those following LKM and WM were assumed to feel better (valence) and be more open (state openness). Social robots could stimulate creativity and reduce negative mood, therefore we expected social robots to be better at that task than audio-guided interventions.

In our study, we found significantly higher positive valence in the meditation groups compared to the group in *rest*, which seems to line up with previous studies demonstrating emotional benefits after LKM and WM (Bigliassi et al., 2020; Edwards and Loprinzi, 2018; Fredrickson et al., 2008; Kok et al., 2013). However, this result solely leaned on those who received LKM with audio guidance. Others did not show significant improvement in valence compared to the control group. Notably, positive effects for valence were only present in the dataset that included negative outliers (cf. Duan et al. 2021).

These results demonstrate four things. First, what media one uses (audio or robot) makes no difference for a change in valence. Second, the treatment itself also does not make a difference on shifting valence. Third, compared to the control group spending idle time, only LKM with audio induced a valence shift. Last, the positive effect on valence was gone without the outliers, indicating with Duan et al. (2021) that those who do not suffer hit a ceiling effect and that spreading love and kindness is good for the most negatively charged people.

Compared to the audio-guided groups, the robot-guided groups did not report bigger changes in valence after the intervention, which may be due to a clash between the physical appearance of the robot

and its synthetic voice. Menhart and Cummings (2022) examined the users' preferences and experiences of meditation guided by different voices. They found that respondents guided by a human voice rated the voice and the meditation exercise as more enjoyable, useful, and more relaxed. In our study, the audio groups were guided by a natural human voice, whereas the robot groups were guided by a synthetic voice. We assumed the physical presence of NAO could benefit the participants in terms of feeling accompanied and in paying attention (Lopez-Caudana et al., 2022; Okafuji et al., 2020) to the exercise. However, the synthetic voice maybe undermined the experience of and engagement in meditation, and thus the accompanying effect, positive valence, was diminished. Indeed, certain participants reported that the voice of the robot distracted them from the meditation.

We selected two types of meditation to induce positive emotion. LKM supposedly generates a positive mindset (Fredrickson et al., 2008) while WM would increase arousal (Edwards and Loprinzi, 2018). Although these approaches work differently, their outcomes should be no different, which is in line with Fredrickson et al. (2008) and Edwards and Loprinzi (2018).

In comparison to the group at *rest*, only audio-guided LKM showed a significant shift towards positive valence. Surprisingly, audio-guided WM did not result in higher valence change. From Edwards and Loprinzi (2018), we were under the impression that LKM would improve the overall mood, while WM could only improve the feeling of fatigue and inertia. Apparently, our mainly non-negative feeling participants had no lack of energy. Another possibility is that WM requires more time to take effect. WM contains activity (i.e., walking), distracting people from the stressor or negative rumination while activating the executive functions of the prefrontal cortex to enhance emotion-regulation capability. After WM, positive valence may not be

an immediate gain and it may require more time for physiological arousal to decrease and so reduce negative emotions (cf. the aerobic exercise of Mandolesi et al. 2018).

Most of our sample consisted of individuals who reported a mild positive valence on average. Our findings imply that the emotional benefits of LKM may be more pronounced for individuals experiencing a strongly negative mood (Duan et al., 2021). This finding aligns with earlier research, suggesting that LKM may be beneficial to those who are suffering from depression and traumas (Hofmann et al., 2011, 2015; Kearney et al., 2021).

Contrary to our hypothesis of increased state openness, we failed to find a significant difference between the treatment and the control groups in their after-intervention scores. However, state openness was significantly higher for treatment groups (with all negative outliers included) than for the control group in terms of difference scores. This finding is in line with Hotchin and West (2020), suggesting that reflecting on positive and novel experiences can increase state openness. The context of the LKM encourages participants to spread benevolent and loving energy to themselves and others, while the WM motivates the participants to experience walking and explore the surroundings. Both seem to make participants more aware of positive and novel experiences, which supposedly opened up their minds. However, when we investigated the differences between treatment groups, we found that the effect on openness came from audio-guided meditation: A human-recorded voice seems to be recommendable to open people up.

Audio-guided meditation can improve state openness. However, if valence also needs to be improved, the audio should be integrated into a Loving-Kindness Meditation. Although meditation and media did not work as expected for the correlated state openness and

positive valence, these treatments did increase the willingness to create. The key point was the final state of valence and openness rather than the gain after the intervention. The change of the state did not predict the change of willingness in the same direction. This indicates that there could be a threshold of state valence and openness to activate the creative pursuit. Even though some of our participants were less positively emotional and open-minded than they were before the treatment, they remained at the same level of willingness to create because they still superseded scale threshold (> 3).

Notably, participants with more positive valence and higher state openness showed a higher willingness to engage in creative activities. This finding is consistent with previous research, indicating that people with happiness and feeling of being active (Silvia et al., 2014) and openness (Tan et al., 2019) are more intrinsically motivated to pursue creativity. Additionally, individuals with higher positive valence demonstrated better performance in convergent thinking. This ties in well with the tendency that positive valence enhances cognitive fluency, information processing speed, and response level (Rooij and Vromans, 2020). However, neither positive valence nor higher state openness was associated with improved performance during convergent thinking. Convergent thinking involves finding a single solution, whereas divergent thinking entails generating multiple ideas (Colzato et al., 2014). In contrast to Big-C creativity, everyday creativity is typically triggered by less complex problems that arise from everyday situations (Cunha and Clegg, 2019) and require less time and insight to generate solutions (Sawyer et al., 2003). Probably, convergent thinking is more likely to be utilized in every creativity. Richards's model of everyday creativity (2007) says that creativity is both a cause and an effect of human flourishing. That together with our current findings suggest that

interventions aimed at enhancing positive valence and state openness may contribute to human well-being, whether through robot intervention or not.

Even so, one may contest the relationship we stated among being open, creative, and being in a positive mood because many artists who have suffered a lot in their lifetime made great artworks with that suffering as their topic or worked even from unkind considerations such as rage and revenge (cf. Dante's *Divine Comedy*). However, there are two things to consider:

First, our participant group did not consist of artists or other Big-C creative people (Csíkszentmihályi, 1996) and so they fell under the empirical finding in creativity literature that a positive mood opens the mind, leaving more room for creative associations and solutions to occur (cf. Broaden-and-Build theory, Fredrickson and Branigan, 2005). Indeed, looking into the moderators of creativity, the literature from diverse disciplines shows overwhelming evidence that positive circumstances enhance explorative and creative behaviors, whereas negative situations subdue creativity; fear, sadness, and social exclusion being among those disadvantageous factors (e.g., Bassett-Jones 2005, Beghetto 2010, Chua 2007, Csíkszentmihályi 1996, Fredrickson and Branigan 2005, Heilman et al. 2003, Mayer 1999, Nickerson 1999, Plucker and Renzulli 1999, Puccio and Cabra 2010, Savransky 2000, Schweizer 2006, Schweizer et al. 2006, Sternberg and Kaufman 2010, Ward et al. 1999, Williams and Yang 1999, Zander and Zander 2002).

Second, while in suffering or in a negative mood, Big-C people are not capable of creation either because they are forced into survival mode, allowing for mainly flight, fight, and freeze action-tendencies (e.g., Schweizer et al. 2006). However, afterwards, in a more relaxed

state of mind, Big-C people are capable of using bad experiences as materials for creation, making us intensely feel their emotions (rather than their creativity).

With respect to interaction theory, CASA (Computers as Social Actors; Nass and Moon, 2000; Nass et al., 1994) would expect that a social robot evokes a higher level of anthropomorphism and social presence compared to audio alone. NAO should be better at mobilizing participants' engagement in the exercises than audio. However, NAO did not do better in eliciting positive valence and openness. CASA-related findings regarding the social treatment of technology may not be as enduring as considered in the early days, as the schematic processing of mediated interactants may change in light of the emergence of new technologies, new modes of interaction, and new media images about social interactions (Gambino et al., 2020). With more knowledge about technology, young adults are more easily aware of the machine behind the anthropomorphism (Gambino et al., 2020). Although the physically present NAO provided more social-presence cues than audio, the synthetic voice distracted participants from the activities. It is more about task-alignment of certain features being humanlike than their sheer presence or number.

8. Limitations

Our sample consisted of young adults who were generally healthy, rather than those clinically suffering from a negative mood. This may have limited the extent of valence improvement observed, as the meditation exercises were not designed to elicit extremely positive emotional states. Additionally, there may have been unaccounted training differences between participants, with those who had prior experience in meditation, potentially having an advantage in ease of practice and task focus (Bailey et al., 2019). It is important to note

that there were discrepancies in the sample sizes between experimental groups ($n \geq 55$ for LKM and WM) and the control group ($n = 29$ for Rest) (Table 3). Rather than an experimental design defect, such dependency coupled with unequal variance *t*-tests may have led to an increased likelihood of Type I errors, falsely resulting in rejection of the Null hypothesis for the rest group (Ruxton, 2006). However, further inspection of results showed that the significance of effects leaned towards the audio-meditation group. Because we did not use the results of the treatment groups as a whole against the control group, our main findings are not distorted by a potential sample-size deficit. Furthermore, more participants in the robot group received higher education but the correlations between mental state measurements and education or with any other demographic variable were not significant.

Notably, our work relied on a single stimulus per condition, which may limit the generalizability of the findings (Reeves et al., 2015). We used a NAO machine but maybe another type of robot (e.g., iCub) may have rendered different results. As far as we are aware, there is not a real body of evidence to refer to, but it is our experience that if a robot's appearance is not sensitive to the task, it does not matter much what embodiment (cf. the voice guide) to use as long as its features (cf. the more humanlike voice) and behaviors functionally relate to the task at hand, here, to offer guidance in relaxation. Of course, one may make the point that, for example, a robot mimicking a yoga guru may do better but that may be a trap as well because people start to increase their expectations only to find that the robot's performance is disappointing. In future work, researchers may want to experiment with the dos and don'ts of using different robots in relaxation tasks.

According to Gross and Thompson (2014) as well as Koole and Rothermund (2011), the voice type utilized by an agent, whether

embodied or not, should be tailored to the specific activity to more accurately reflect the demands of daily life. Consequently, it would be valuable to investigate the impact of media agents across a range of tasks, to identify the design of social cues and elements that have a general influence, as well as those that are specific to particular tasks.

The NAO robot was different from the voice agent in physical presence (more so for NAO) and human-likeness of the voice (more so for the voice agent). One way to deal with this is to use a human-recorded voice for the robot, however, it may be that a toy-like NAO robot is not supposed to have a human voice. To compensate for this, we may want to use a more humanlike robot like Ishiguro's Erica but at running the risk of overestimation of capabilities and getting trapped in the Uncanny Valley (Mori, 1970). In order to maintain consistency in the vocal characteristics across both the audio and robot conditions, one option would be to use a synthesized voice for the audio condition. However, natural human voices are commonly used in online audio-based meditation, and we aimed to avoid creating an atypical condition for comparison. We acknowledge that the inconsistency in voice type may have influenced our findings. Therefore, in future work, we will explore a balanced approach to ensure consistency in content and tone while still allowing the robot to deliver the audio naturally. This may involve identifying a voice type that bridges the gap between natural human speech and synthesized robotic speech, providing a more controlled comparison between the two conditions.

Some may think that our text-based creativity measurement could be unfavorable to those who are more visually oriented. Creativity is a multifaceted concept that involves different cognitive processes and abilities; it can be expressed in both linguistic and visual mediums. Individuals with high visual-spatial intelligence can also be

highly creative in verbal domains, such as creative writing or poetry (Kaufman and Baer, 2004). In our study, participants provided an extra word to create three two-character words in RAT and listed alternative uses for objects in AUT. To complete these tasks, participants could make use of mental imagery and imagination. From this perspective, these tasks can be perceived as a form of 'visual' art. Also, linguistic creativity is less domain or task-specific and does not require that one possesses skills in drawing or sculpting (Palmiero et al., 2015). Thus, text-based tasks may be suitable for measuring the daily creativity capability of the public.

Another concern regarding robot-guided meditation is the effect of familiarity or novelty in robot interaction. While Shibata et al. (2011) discovered that participants reported higher levels of enjoyment and engagement when they interacted with a novel robot in a guided relaxation exercise, Park et al. (2019) evidenced the novelty of a robot could be distracting during a guided meditation. The novelty effect of robot interaction may exert an influence on the outcomes of our single-session experiment, although the polarity of the effect remains indeterminate. Nonetheless, we postulate that the variability of this effect among participants is minimal, considering the limited exposure of NAO robots to the general public. Future investigations could examine whether the findings of our research differ for individuals who have engaged in multiple interactions with a NAO robot. Increased familiarity with the robot might attenuate the novelty effect, subsequently exerting a diminished impact on the meditation experience.

State openness refers to the momentary viability of *trait* openness. Individuals low on trait openness may sometimes express relatively high states of openness (Fleeson, 2001; Fleeson and Jayawickreme, 2015). Trait openness is typically measured by a sum of scores from various constructs. However, it should be noted that

despite having a low overall trait openness score, an individual may still exhibit openness in a specific field or context (Hirsh et al., 2009). In our study, only two participants reported trait openness below 3.75 (but still beyond 3). We unfortunately did not have enough samples to explore the influence of trait openness on state openness. For instance, higher trait openness is already strongly associated with an interest in engaging in meditation (Van den Hurk et al., 2011), and therefore, experiencing greater state openness may be less likely to have an additional influence on the meditation effect. Further research could examine the extent to which these findings of openness apply to those young adults who approach pathological levels of narrow-mindedness, such as depressed individuals having a rigid and inflexible thinking style (Beck, 2008; Disner et al., 2011).

Moreover, there may be unresolved concerns regarding two aspects that could affect participant engagement in meditation. The English language instruction employed in the meditation may have posed a challenge to non-native speakers. However, English is an official language in Hong Kong and the language we used in meditation was simple. Moreover, we demonstrated that the audio-guided LKM was effective in achieving a relatively positive effect. Please note that the length of the instruction in LKM was longer than in WM, suggesting that the English instruction may not have hindered participants' understanding.

Additionally, the awareness of being observed during a lab activity may impact behavior, which is a concern of lab experiments in general (i.e., Hawthorne Effect; Landsberger, 1958). However, this was more of a problem in the at-home exercise of the pilot study where participants may not really have engaged with the meditation and reported inaccurate experiences, leading to erroneous results. In all, we explored the effects of different types of meditation and media to boost daily creativity via positive valence and state

openness. Our focus was not on which setting (at-home, in-lab) encourages people to engage in their daily lives. To this end, lab experiments allow us to manipulate and control variables and find effects of people participating in meditation.

In summary, among the limitations we mentioned, some of them are general lab experiment limitations (e.g., single stimulus per condition, limiting generalizability), while some arose from deliberate choice (e.g., text-based creativity measurement potentially unfavorable for visually oriented participants). Some limitations, like unanticipated confounding variables and recruitment challenges, emerged during data collection and analysis. For the limitation concerning the robot's novelty and participants' meditation experience, we understand their potential influence on the intervention experience. However, to minimize participant stress during the questionnaire task, we kept the number of items minimal.

9. Conclusion and further work

We found that WM and LKM improved state openness, while audio-guided LKM led to a positive change in valence as well. Valence and state openness are positively correlated, and both stimulate the willingness to create. However, openness rather than the improvement of valence contributed to better performance in convergent thinking. Thus, individuals who are in a sad mental state, regardless of the level of improvement, seem to be willing to pursue daily, convergent, creativity. Given that the pursuit of daily creativity causes whole-life well-being (Richards, 2007), the clinical implication of our study may be that LKM and WM are beneficial for negative mood reduction, also when transmitted through media.

Notably, mediated LKM works for people with strong negative valence while WM targets fatigue. Moreover, the positive change in

openness may not be restricted to a subset of people (i.e., outliers) but may happen in the larger audience as well. Being more open and in a better mood may stimulate participants to explore the activities a therapist offers, and so mediated therapy may be a good precursor to actual treatment. During actual consultation, these benefits may also enhance performance and motivation in convergent tasks, such as problem-solving treatment (Gask, 2006).

Our NAO robot did not enhance creativity, openness, and positive valence. That does not mean that other robots or robots in different settings never will. Afonso (2020) showed that positive changes in brain areas that are involved in stress and anxiety arise only over longer periods of time. Fredrickson and Branigan (2005) also emphasize that flourishing occurs over a longer period. Long-term treatment of participants diagnosed for emotional distress, depression, or clinical negative mood may well benefit from robot therapy. Clinically depressed populations are characterized by being closed-minded (Disner et al., 2011; Beck, 2008). Their low mood is proportionally due to emotional fatigue (Fava, 2003). In surveying this type of closed-minded participants, we could investigate the effect of meditation on different levels of frustration.

Therefore, future research may want to address several key aspects to expand upon our current research and improve the generalizability and applicability of our findings. First, we will incorporate longitudinal study designs to better understand the long-term effects of the variables under investigation. By conducting multiple sessions of media-guided meditation interventions spread over weeks or months and encouraging them to solve the problems in life creatively, we aim to assess the cumulative impact of these interventions on participants' positive valence, state openness, and everyday creativity performance (in terms of willingness and ability). This approach will provide valuable insights into the sustained benefits of

media-guided WM and LKM mediation practices. After we examine the mental health maintenance effects of mediation among the general public, we may conduct studies with clinical samples, specifically individuals diagnosed with depression or other mental health disorders. By including participants with diverse mental health profiles, we can better understand the potential therapeutic effects of media-assisted mediation intervention and how they may differ across various populations. This will contribute to the development of more targeted and effective interventions for specific mental health conditions. With the knowledge gained from the first two future studies, we recommend exploring the potential of personalized robotic interactions tailored to different individuals' differences, such as trait mindfulness, habit of mediation, and mental health needs. Minor improvements will be made to our future studies, such as improving the consistency of the audio across different media conditions. By addressing these aspects in our future research, we hope to significantly understand the media-assisted WM and LKM interventions' potential benefits for promoting well-being and creativity across diverse populations.

Young adults in Hong Kong are under high pressure from work, study, society, and family. Deteriorated mental health during and after COVID-19 is a global issue (Shorey et al., 2021). People with low social-economic status, as well as quite unexpectedly, youngsters and students are at risk of loneliness and negative mood. Online intervention avoids contamination issues and is a solution for those who are socially isolated and not capable of finding human help. Our study showed the benefit of certain types of meditation guided by a voice-agent. Physical robots may add to the effect but designing their affordances in line with the task is no trivial matter. As a long-term goal, we strive for the design of a personal friend for life that vulnerable young adults can confide in a safe and secure way

with wholesome maintaining and therapeutic effects on their well-being. We hope for a mentally healthier and more stable population, less prone to social unrest and more resilient to setbacks.

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CRediT authorship contribution statement

Ivy S. Huang: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Yoyo W.Y. Cheung:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Johan F. Hoorn:** Methodology, Validation, Formal analysis, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Consent form

Negative-mood Reduction With Robot Through Creativity

I hereby consent to participate in the captioned research conducted by Prof. Johan Hoorn. This study was performed as part of the PAL project (Personal Avatar for Life) of the Laboratory for Artificial Intelligence in Design (AiDLab) (Grant No. AiDLab R2P3).

I understand that information obtained from this research may be used in future research and published. However, my right to privacy will be retained, i.e. my personal details will not be revealed.

The procedure as set out in the attached information sheet has been fully explained. I understand the benefits and risks involved. My participation in the project is voluntary.

I acknowledge that I have the right to question any part of the procedure and can withdraw at any time without penalty of any kind.

Sign box

Appendix B. Questionnaire

Structured questionnaires of the interventions are listed below in English. Supplementary materials (Technical Report) include the questionnaire in Chinese and the script in both languages.

Before Intervention (QS1)

* Participants have to choose from a 6-point rating scale: *Strongly disagree, Disagree, Slightly disagree, Slightly agree, Agree* and *Strongly agree*.

Please tell us truthfully how you feel at the moment.*

1

I feel good.

2

I am well.

3

I have positive feelings.

4

I am optimistic.

5

I feel bad.

6

I am unwell.

7

I have negative feelings.

8

I am pessimistic.

Please choose the most suitable answer that can describe your situation in the past 30 min.*

1

I suppressed my thoughts.

2

I let my thoughts be.

3

I accepted what I felt.

4

I rejected what I felt.

5

I noticed my emotions.

6

I ignored my emotions.

7

I was aware of my ideas.

8

I was unaware of my ideas.

Please choose the appropriate answer to describe your thoughts at the moment.*

1

I am willing to participate in creative-related activities.

2

I am inclined to do regular tasks.

3

I am reluctant to do something creative.

4

I am pleased to express my ideas or feelings in a novel way.

Alternative Uses Task

In this test, we will list some common objects. Each object has a common use, which will be stated. Your mission is to list as many as six other uses of the object.

Example: A NEWSPAPER (used for reading)

Your possible answer:

1

Start a fire

2

Wrap garbage

3

Swat flies

4

Stuffing to pack boxes

5

Line drawers or shelves

6

Make up a kidnap note

Notice that all of the uses listed are different from each other and different from the primary use of a newspaper. Each acceptable use must be different from others and the common use.

After clicking ‘Next Page’, you will see three common objects. You are given 4 min to answer, you can use English or Chinese to answer. When time is up, the next page will automatically appear. Please try your best to complete more questions, do not spend too much time on any one item. To avoid affecting the experiment result, do not use any assistant tool to search for answers.

1

Please list out the other six uses of SHOE (used as footwear).

2

Please list out the other six uses of BUTTON (used to fasten things).

3

Please list out the other six uses of KEY (used to open a lock).

Remote Association Test

In this test, each item comprises 3 ‘stimulus words’. Your mission is to come up with a ‘target word’ that could combine with all three stimuli to create three actual two-character words.

Given (Stimulus words): 療, 防, 統.

Answer (Target word): 治.

Explanation: The answer is 治 and the actual two-character words are 治療, 防治, and 統治.

After clicking ‘Next Page’, you will see ten questions. You are given 4 min to answer. When time is up, the next page will automatically appear. Please try your best to complete more questions, do not spend too much time on any one item. To avoid affecting the experiment result, do not use any assistant tool to search for answers.

Please enter the ‘target word’ in the blank.

1

問,案,應

2

存,女,寫

3

留,圖,隨

4

代,童,級

5

移,態,舉

6

源,將,信

7

印,園,費

8

派,改,端

9

黑,具,德

10

目,折,歌

After Intervention (QS2)

* Participants have to choose from a 6-point rating scale: *Strongly disagree, Disagree, Slightly disagree, Slightly agree, Agree* and *Strongly agree*.

Participants have to choose an item.

The intervention ends. Please tell us truthfully how you feel at the moment.*

1

I feel good.

2

I am well.

3

I have positive feelings.

4

I am optimistic.

5

I feel bad.

6

I am unwell.

7

I have negative feelings.

8

I am pessimistic.

Please choose the most suitable answer that can describe your situation during the intervention.*

1

I suppressed my thoughts.

2

I let my thoughts be.

3

I accepted what I felt.

4

I rejected what I felt.

5

I noticed my emotions.

6

I ignored my emotions.

7

I was aware of my ideas.

8

I was unaware of my ideas.

Please choose the appropriate answer to describe your thoughts at the moment.*

1

I am willing to participate in creative-related activities.

2

I am inclined to do regular tasks.

3

I am reluctant to do something creative.

4

I am pleased to express my ideas or feelings in a novel way.

Alternative Uses Task

In the following, we will list another three common objects. Again, your mission is to list as many as six other uses of the object.

After clicking ‘Next Page’, you are given 4 min to answer. When time is up, the next page will automatically appear. Please try your best to complete more questions, do not spend too much time on any one item. To avoid affecting the experiment result, do not use any assistant tool to search for answers.

1

Please list out the other six uses of PENCIL (used for writing).

2

Please list out the other six uses of AUTOMOBILE TIRE (used on the wheel of an automobile).

3

Please list out the other six uses of EYEGLASSES (used to improve vision).

Remote Association Test

In the following, we will list out 10 questions. Again, your mission is to come up with a ‘target word’ that could combine with all three stimuli to create three actual two-character words.

After clicking ‘Next Page’, you are given 4 min to answer. When time is up, the next page will automatically appear. Please try your best to complete more questions, do not spend too much time on any one item. To avoid affecting the experiment result, do not use any assistant tool to search for answers.

1

亮,照,星

2

倒,超,票

3

感,號,港

4

算,手,知

5

牌,現,錢

6

尾,養,稅

7

解,原,論

8

政,通,善

9

航,產,運

10

餐,信,戶

Please choose the appropriate answer to describe your situation during the intervention.*

(Walking Meditation Group)

I follow the instructions during the meditation.

I am able to let my mind wander during the meditation.

(Loving-kindness Meditation Group)

I follow the instructions during the meditation.

I am able to generate a feeling of kindness during the meditation.

(Rest Group)

I followed the instructions and took a rest on the seat

I participated in other activities besides taking a rest, e.g. using a mobile phone

Please choose the appropriate answer to describe you.*

1

I am open to novel experiences.

2

I am open to new methods to solve problems.

3

I am open to opinions from others.

4

I am open to what is different from my belief.

What is your gender?#

Male

Female

Others

Where do you come from?#

Hong Kong

Mainland China

Others

What is your age?#

20 or below

21–25

26–30

Above 30

What is your highest educational level?#

Primary school or below

Secondary school

Post-secondary school / Associate Degree / Diploma

University or above

Appendix C. Scripts

Loving-kindness Meditation Script

Robot-guided Group

Hi, my name is Zora, how are you today?

Audio-guided Group

Hi, how are you today?

We are now going to start meditation for 10 min. It's about kindness and the desire for someone to be happy, or for yourself to be happy.

If you find yourself getting distracted...that is fine...just return to the script. There is no right or wrong way to do this exercise, just feel free to relax as you go through the experience.

To begin this practice...Let yourself be in a relaxed and comfortable position. You can check your body and notice how you're feeling right now...Letting whatever is here, be here...If you find it hard to concentrate, you can try to put your focus on a particular point.

Now let yourself bring to mind...Someone whom, the moment you think of them, you feel happy...You can pick your parents or best friend...a dog or a cat...Just let them come to mind

Have them - have a sense of them being in front of you...You can feel them, sense them, see them...Just observe your experience... whatever it is...

And as you imagine them...Notice how you're feeling inside...Maybe

you feel some warmth...Or there's some heat to your face...

A smile, a sense of expansiveness...This is kindness...This is a natural feeling that's accessible to all of us at any moment

So now having this loved one in front of you...Begin to wish them well

May they be safe...

May they be happy...

May they be healthy and strong...

May they have ease and wellbeing...

And as I say these words, you can use any words or your own words

May they be safe...

May they be happy...

May they be healthy and strong...

May they have ease and wellbeing...

Have a sense of letting this kindness come from you...And begin to touch this loved one...Reaching out...You may have a sense of light, color, or just a feeling.

...And so as you're sending out these words and these feelings of kindness...Also, check yourself and see how you're feeling inside...

Now imagine that this loved one turns around... And begins to send love back to you...So see if you can receive the kindness

Take it in...And they're wishing you well:

May you be safe…

May you be happy…

May you be healthy and strong…

May you have ease and wellbeing…

Now…you can send kindness to yourself…You can imagine it coming down your body from your heart…You can just have a sense of it

May I be safe…

May I be happy…

May I be healthy and strong…

May I accept myself just as I am…

And as you ask yourself the question “what do I need to be happy?” …See what arises… And offer that to yourself…May I have meaningful work…A joyful life…Close friends and family

Now, checking into yourself…And notice what you feel as you do it

And now let yourself bring to mind one person…Or a group of people that you wish to send the kindness to…Imagine them in front of you… Sense them, feel them

May you be peaceful…

May you be free from all stress and anxiety and fear…

May you have happiness…

May you be peaceful…

May you be free from all stress and anxiety and fear...Worry...Grief...

May you have happiness...Wellbeing

Now let this kindness expand out...Spreading...Touching anyone that you want to touch right now...In all directions...People you know, people you don't know...People you have difficulty with...People you love...

Just imagine expanding and touching ...And each person or animal ... Whoever is touched by this kindness...Each person is changed...You can imagine that

So may everyone everywhere be happy and peaceful and at ease...

Robot-guided Group

Now the meditation ends. When you are ready...you can continue to the next process.

Audio-guided Group

Now the meditation ends. When you are ready...you can go back to the seat and continue to the next process.

Walking Meditation Script

Robot-guided Group

Hi, my name is Zora, how are you today?

Audio-guided Group

Hi, how are you today?

We are now going to start a walking exercise for 10 min. The goal will

be to freely experience walking and explore the surroundings. If you find yourself getting distracted…that is fine…There is no right or wrong way to do this exercise, just feel free to relax as you go through the experience.

Now, take a look at the marker on the floor.

Robot-guided Group

All you need to do later is to stand on top of the mark and keep walking on the spot. Let me show you how to do it (Walking demonstration). Got it? It's your turn now. Go stand on top of the marker, slowly, start walking on the spot.

Audio-guided Group

Now, you can go and stand on top of the mark, then keep walking on the spot.

Please keep walking, I will let you know when the activity ends.

Well done. Just keep walking.

Keep walking. Take a deep breath, relax, and find yourself a comfortable way of walking. Place your hands wherever you feel comfortable, you can put them at your sides, behind your back, or on your belly.

Place your attention on your feet and observe walking as you did the first time. Be curious, focus your attention on the process of walking as you lift, move, and place your feet down.

Now, relax your mind, and allow all your senses to become absorbed in the park. Simply experience whatever you sense in the environment…… See how green the tree is, feel the sunlight dancing

on the leaves, hear the sound of the small insects.

Don't judge the experience, try to remain immersed in walking in the park.

Simply continue...with your walking, and let your mind wander...Think about whatever you want. You can continue your exploration in the park, or, think of something else.

Just let your mind wander freely...without trying to focus...on anything particular...I'll let you know...when it's time to move on to something else...

Continue walking and letting your mind wander...letting your thoughts go wherever they take you...

Think about whatever you want...go ahead and follow whatever thoughts come to mind...

Allow your thoughts to wander...wherever they may go...

Simply continue.....with your walking, and let your mind wander... Think about whatever you want...go ahead and follow whatever thoughts come to mind...

Now, the meditation ends. When you are ready, you can stop walking, go back to the seat and continue to the next process.

Data availability

Data will be made available on request.

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