Computers in Human Behavior 99 (2019) 345–351

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Which EEG feedback works better for creativity performance in immersive virtual reality: The reminder or encouraging feedback?

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ARTICLE INFO

Keywords:
Creativity
Feedback
Electroencephalography
Immersive virtual reality

ABSTRACT

The purpose of this study is to investigate whether the feedback designed based on EEG (electroencephalography) signals contributes to an individual's creative performance in an immersive virtual reality setting. Two specific forms of feedback were used. The first one was “reminder feedback,” given when brainwaves indicated the participant's attention was not concentrated. The second one was “encouraging feedback,” given when brainwaves indicated that the participant's attention was very concentrated. Sixty high school students were randomly assigned to participate in an open-ended design challenge in an immersive virtual reality setting. Twenty (N = 20) participants received no feedback; twenty (N = 20) participants received reminder feedback; and another twenty (N = 20) participants received encouraging feedback. Findings showed that the participants who received reminder feedback had higher-quality creative products than those in a group with no feedback or encouraging feedback. In addition, EEG feedback also had an impact on the participant's attention and flow state. These findings are discussed in terms of feedback impacts, study limitations, and future research directions.

1. Introduction

Emerging technologies are redefining human work, and the workplace is changing into a hybrid space of virtual and actual realities (Thorsteinsson & Page, 2007). With all the newer technology potentials and challenges, educators around the world are paying more attention to developing students' creativity (Fasko, 2001). Creativity is studied in a wide range of fields, including individual traits, neurology, cognitive science, and the social environment (Amabile & Pillemer, 2012). In this study, we pay attention to ways to facilitate creativity in individual creative processes. Previous studies have shown that an individual's attention and mental state in activities affect their creative performance (Silvia et al., 2014). Studies have shown that attention is closely related to flow state (Connolly & Tenenbaum, 2010). Previous studies also found that the higher the attention, the easier it is to enter the state of flow, and the better the individual's creativity will be (Yang, Lin, et al., 2018).

The question is, can individual attention in activities be influenced by feedback, thereby improving an individual's state of flow and the individual's creative performance? Studies have shown that EEG (electroencephalography) feedback can improve the attention of a participant in the reading process, and can affect the individual's reading performance (Lin, Lai, Lin, & Wu, 2014). Relevant research has shown that positive and negative feedback are given according to the levels of attention of the participants, which help the participants to achieve better learning results in English learning (Chen & Huang, 2014; Kuo, Chu, & Tsai, 2017). However, can different EEG feedback methods affect the processes of individual creativity?

An immersive virtual reality setting can provide a new entry point for researchers to study social science issues (Fox, Arena, & Bailenson, 2009). As such, data that are more precise can be captured and more social science research can be conducted without ethical concerns (Parsons, Gaggioli, & Riva, 2017). Thus, the feedback intervention strategy in the virtual reality environment can be more deliberate, controlled, and accurate. The new technologies can also help researchers to collect participants' brainwave data in real time to study their attention, flow and creativity under different feedback strategies.

For this study, we aimed to investigate whether EEG feedback contributed to an individual's creative performance in immersive virtual reality settings. We used an experimental approach to understand

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https://doi.org/10.1016/j.chb.2019.06.002
Received 15 February 2019; Received in revised form 4 June 2019; Accepted 6 June 2019
Available online 06 June 2019
0747-5632/

the effectiveness of two specific forms of feedback on the qualities of creative products, flow state, and attention. The first one was named "reminder feedback," given when the brainwaves indicated that the participant's attention was not concentrated. The second one was named "encouraging feedback," given when the brainwaves indicated that the participant's attention was very concentrated. We proposed the following research questions:

- Are there any differences of brainwave states of attention among the individuals in different EEG feedback groups?
- Which EEG feedback help the individuals get into the state of flow in the immersive virtual reality (VR) setting?
- Which EEG feedback contribute to an individual's creative performance in the immersive virtual reality environment?

2. Literature review and related work

2.1. Attention, flow and creativity performance

The word creativity is widely used, sometimes used to praise a work of art, sometimes used to describe a person's ability (Kaufman & Sternberg, 2010). Amabile (1996) defines creativity as an idea or product that is not only original, but also valuable. Despite the broad definition of creativity, most people believe that creativity should be both novel and effective (Paulus, 2000). Individual creativity is influenced by factors such as knowledge, thinking mode, internal motivation, and psychological state (Sternberg, 1999).

Studies have shown that creativity is closely related to attention. If a person wants to create a valuable original product in a certain field, he or she must concentrate their attention during the design process (Nusbaum & Silvia, 2011). The focused attention is beneficial for information processing in the brain, and attentive learners tend to achieve better performance (Smithson, Phillips, Harvey, & Morrall, 2013). Previous studies showed that when people were too stressed, they showed a state of difficulty in concentration, and the output of their work were affected (Nguyen & Zeng, 2012). Studies also showed that highly creative participants were more likely to concentrate during creative processes (Furnham & Bachtiar, 2008).

Through interviews with creative people, Csikszentmihalyi put forward the theory of flow, discussing the psychological state when people were fully committed in the creative processes (Csikszentmihalyi, 2014). The state of flow is a state of immersion wherein people feel the balance between individual skills and challenges. It is characterized by no fear of failure or no awareness of the passage of time. There was a lack or disappearance of self-consciousness. A high level of flow state contributes to a person's creative performance (Pacauskas & Rajala, 2017). Studies also show that maintaining attention is a prerequisite for entering a state of flow, and that attention is closely related to the state of flow (Diaz, 2013). In addition, a study on creativity found that attention, flow, and creativity were significantly positively correlated (Yang, Cheng, Lin, Huang, & Ren, 2018). The more concentrated the attention, and the better the performance of the participant's work can be potentially.

2.2. Attention and EEG feedback

Attention is one of the most scarce resources for an individual in an activity (Falkinger, 2008). In past studies, the concentration of attention was often reported by surveys or interviews, but now it can be measured by EEG brainwave equipment, and the level of attention can be read in the process of an individual's activity (Sauseng et al., 2005).

The sources of feedback are diverse, and most feedback in education come from peers, teachers, and parents (Richardson, 2005). Feedback is often used to improve learning performance (Hattie & Timperley, 2007). Klueger and DeNisi (1996) conducted a meta-analysis of feedback patterns in educational contexts and found that feedback has a positive impact on overall performance. However, there is also a lot of feedback that is considered to hinder participants' learning activities (Klueger & DeNisi, 1996). The effect of feedback on learning activities depends on the feedback method, task objectives, and task complexity (Sansone, 1989).

With the development of technology, new feedback methods are being introduced (Scheeler, Ruhl, & McAfee, 2004). Previous research has pointed out the potential benefits of providing feedback to learners using emerging brain-computer interface technologies (Chen & Huang, 2014). The collection, monitor, analysis and intervention of a learner brainwave data can provide new feedback on learning that may positively affect the learner's learning outcome (Baker & Yacef, 2009). The use of brainwave signals to design feedback mechanisms is called EEG feedback (Seaward, 1999). The design of the feedback mechanism based on the strength of a certain value of an individual's brainwave signal can help the learner maintain attention in a more stable way (Monastra et al., 2006).

At present, research on attention intervened by EEG feedback has been used to train a participant to improve his or her long-term attention levels (Battaglia et al., 2004). This kind of experiment adopts the method of attention monitoring to provide measurement, supervision and feedback according to the measured attention of a person, thus improving the person's attention and helping them to better complete the specified tasks (Monastra, Monastra, & George, 2002). In a study conducted by Lin and his colleagues (Lin et al., 2014), the scholars used the EEG feedback method to help the participants with reading tasks (Lin et al., 2014). Through the study, EEG equipment monitored attention states and provided learners with different attention feedbacks. In another study conducted by Moore (2000), the scholar used different EEG feedback forms such as vibration, visual and audio input. However, most studies used audio as feedback (Lin et al., 2014; Steiner, Sheldrick, Gotthelf, & Perrin, 2011). The use of audio feedback can enhance learning outcomes and has shown to be an effective form of feedback in facilitating task completions. The audio or voice feedback is also a less intrusive but more commonly used form of feedback when EEG is used in learning activities (George et al., 2006). Therefore, this study selected the use of audio feedback as a timely feedback method based on the participant's attention status detected by the EEG device.

Feedback can be divided into two categories – positive feedback and negative feedback (Hattie & Timperley, 2007). Positive feedback can be called encouraging feedback (Mouratidis, Vansteenkiste, Lens, Sideridis, & Psychology, 2008), and negative feedback can be called reminder feedback (Deci, Vallerand, Pelletier, & Ryan, 1991). The encouraging feedback is to inform the participant that the current performance has reached the preset standard or is higher than the standard (Butler, Karpicke, & Roediger, 2007). Research shows that encouraging feedback increases attention during task execution (Luft, 2014), but the extent of the improvement and the impact on the outcome of the task are constrained by the type of task. The reminder feedback is to inform the participant that the current performance has not reached the preset standard or substandard. Studies have shown that reminder feedback can enhance the average level of attention and improve the reading comprehension performance of the participants (Chen & Huang, 2014). However, neither encouraging feedback nor reminder feedback has been used in open-ended creative tasks, and there is no empirical research on whether either type of feedback can enhance the attention of the participants or affect the performance of creativity in such tasks. Previous brainwave feedback research was aimed at textual knowledge as the learning content (Sun & Yeh, 2017), or procedural knowledge presented as animation (Lin & Li, 2018). Therefore, although feedback has shown good impact on improving learners' attention learning textual and procedural knowledge, it is unclear whether similar conclusions can be drawn for an open-ended learning task. In this study, we attempted to send the participants either the encouraging/positive feedback or the reminder/negative feedback based on their EEG brainwave signals, and to explore the effects of such feedback methods on the participants' creativity performance.

3. The development of an EEG feedback system connected to virtual reality

The EEG feedback and Immersive Virtual Reality integrated system in this study consisted of the HTC Vive Virtual Reality equipment and the NeuroSky brainwave equipment. The Immersive VR in this experiment provided the participants with 3D virtual space, digital interactive tools, and 3D models as creative supports (Burdea & Coiffet, 2003). The HTC Vive VR was one of the industry's recognized high-quality immersive VR devices. The system consisted of the following three parts: The first part included the HD head display. The resolution of this display was 1080 × 1200 pixels. At the same time, the head display had a multi-point positioning device, so that the locator could track the position of the user's head in real time according to the positioning device. The second part included two spatial sensors which allowed the users to interact in a 3D space. The users could move, jump, and squat in the real space to directly interact with the virtual space. The third part included a pair of interactive control handles that allowed hand operations to interact directly with virtual reality scenes. The sense of presence in virtual reality was enhanced through the buttons and interactions on the interactive handles. As shown in Fig. 1 below, the participants were creatively designing in the immersive VR (Fig. 1).

Each of the participants' attention value was recorded and measured during their activities via the NeuroSky brainwave device. The device detected electrical signals and transmitted them into a computer, which translated the signals into attention values through an algorithm and kept a record of the them via a specific computer program (Chen & Wu, 2015). The NeuroSky Headset has been used to monitor and measure the attention and meditation of the learning processes (Chen, Wang, & Yu, 2017; Chen & Wu, 2015; Shadiev, Wu, & Huang, 2017; Sun & Yeh, 2017; Zhang, Fruchter, & Frank, 2017). NeuroSky is a lightweight brainwave headset device. After the algorithm calculation, the attention of the brain can range from 0 to 100. The higher the value, the more concentrated a participant is; in other words, if the value is low, the participant is in a state of inattentiveness.

A pre-test pilot study was conducted to determine the threshold when a reminder or encouraging feedback would be necessary. Previous studies have indicated that the attention value ranging 40–60 was generally considered as normal, that the attention value 0–20 was considered as a low attention state, and that the attention value of 20–40 was a relatively low attention state. A high attention state would range between 60 and 80, and the very high attention state was 80–100 (Zhang et al., 2017). In previous studies, researchers set an attention threshold of 40, which triggered feedback when the participant's attention was below 40 (Kuo et al., 2017). Therefore, according to the two different types of feedback strategies discussed earlier, we decided to provide a participant with a reminder feedback when his or her attention value was less than 40 and lasted longer than 4 s in our pilot study. We provided the encouraging feedback when a participant's attention value was over 60 and the duration was longer than 4 s in our pilot study.

As for the content of the encouraging or reminder feedback, we wanted to ensure that the feedback would achieve either the positive or the negative effect. To do this, the research team sought advice from experts and teachers. According to the feedback model and expert advice, the content of the reminder feedback should be concise and clear, designed to help the participant understand the exact meaning of the sound in the shortest period of time, without ambiguity. In addition, the reminding voice feedback and the encouraging voice feedback should not only focus on getting attention from the participants, but they also need to be more closely related to the creativity theme. Therefore, we designed the reminder feedback in the way that not only it called attention from the participants, but it also reminded the participants to think more about new ideas and solutions. We designed the encouraging feedback in the way that not only it affirmed the participants that they were paying attention, but also it praised the participants of their ideas and solutions. After a pilot study, we decided on two voice/audio feedback for the reminder or encouraging feedback: 1) Reminder feedback: when a participant's attention value was below 40, he or she would receive the audio/voice feedback as "Please pay attention! You will come up with good ideas if you pay attention." 2) Encouraging feedback: when a participant's attention value reached above 60, he or she would hear the audio or voice feedback "You are doing great! Please keep up with your great ideas!"

3.1. Pilot study

In order to test whether the above mentioned setting was appropriate, we conducted a pilot study. Four volunteers were selected as participants, including two male and two female high school students. They each wore an integrated system of virtual reality and EEG feedback to complete a 5-min open design task. During the design task, random attempts were made according to the two feedback mechanisms set above. Afterwards, the four participants were interviewed, who provided suggestions for the research team. The participants made specific suggestions regarding the frequency of the feedback provided.

The participants in the pilot study reported that the feedback voice occurred too frequently. In previous studies, the researchers set an interval time between repeated feedback (Sun & Yeh, 2017). All things considered, we adjusted the duration of the brainwaves below or above the threshold from 4 s to 5 s. We adjusted and set to not repeat the feedback sound within 10 s. Finally, two different feedback rules were designed as follows (as shown in Fig. 2):

(1) Reminder feedback: When a participant's attention value was lower than 40, and the duration was longer than 5 s, the participant would

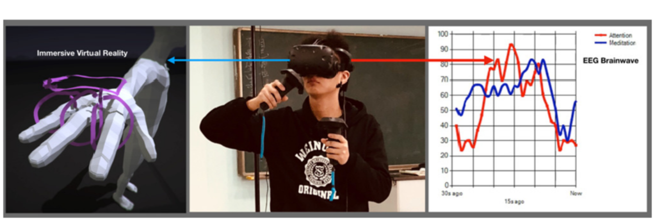

Fig. 1. The participant was designing a wearable device in the EEG feedback and immersive VR integrated system.

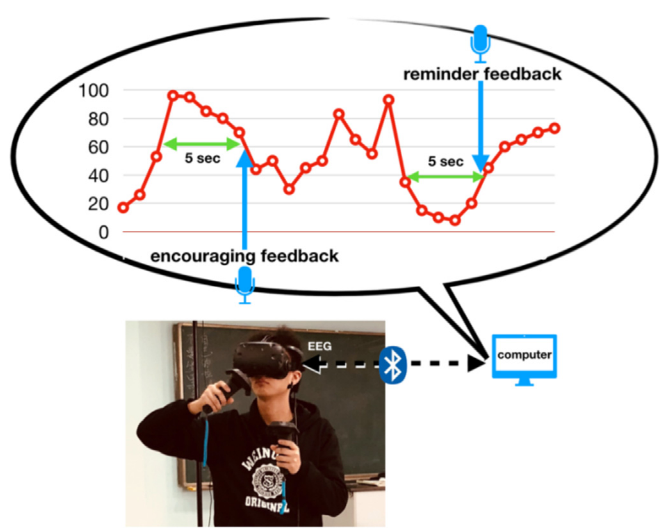

Fig. 2. Feedback sound strategy based on brain wave attention value.

hear a reminder feedback sound: "Please pay attention! You will come up with good ideas if you pay attention." The feedback voice was set so that it would not repeat within 10 s.

(2) Encouraging feedback: When a participant's attention value was over 60 and the duration was longer than 5 s, the participant would hear an encouraging feedback voice: "You are doing great! Please keep up with your great ideas!" The feedback voice was set so that it would not repeat within 10 s.

4. The design of the main experiment

4.1. Participants

In order to explore the impacts of feedback on creative performance, we took an experimental approach with participants who were high school students. A total of 85 high school students were invited to participate in the open-ended design challenge of immersive virtual reality, each in one of the three designed conditions (no feedback, reminder feedback, or encouraging feedback condition). The participants each took turn to participate in the study; that is, there was only one student to participate at the study at any given time in one of the conditions. In the process, some participants did not stay for the entire 5 min of the experiment due to technical issues; some participants were not able to wear the EEG devices because of their earrings; and some participants dropped their EEG devices due to excitement or other reasons. The data from these participants were excluded. As a result, a total of 60 participants' data were valid and used for analysis in this study. The students took turns to participate in the study, that is, if the first student participated in no-feedback condition, the second student would be in the reminder condition, and the third student would be in the encouraging condition. Consequently, the three conditions were randomized into three groups: the group with no feedback ($N = 20$) including 8 female and 12 male students; the group with reminder feedback ($N = 20$) including 9 female and 11 male students; and the group with encouraging feedback ($N = 20$) including 10 female and 10 male students. All participants wore brainwave feedback and virtual reality systems, and they completed the creative design activities, during which, different groups were intervened by different feedback strategies.

4.2. Experimental procedure

The entire experiment process is shown in Fig. 3. Before getting into the virtual reality system, and starting the design activity, the participants each were asked to complete a demographic information survey and to fill out a copy of the Kaufman Domains of Creativity Scale. After that, each participant entered the virtual reality environment constructed for this experiment by putting on the integrated device. The system provided an immersive virtual reality for each participant to create a wearable device using virtual tools, including multiple types of virtual brushes and a 3D human model, with virtual space around the model. Before each participant started their creative activity, they learned how to use different tools in the integrated system. On average, the participants learned to use the interactive tools in the integrated virtual reality system in about 2 min with the help of the researchers. As mentioned earlier, the only difference between the three conditions was the difference in feedback. There was no feedback for the individuals grouped in the first group. The second group of individuals received the reminder feedback, the audio/voice feedback – "Please pay attention! You will come up with good ideas if you pay attention" provided when an individual's brainwave indicated that his or her attention was not concentrated enough (attention < 40, and lasted for 5 s). The third group of individuals received the encouraging feedback, that is, they received "You are doing great! Please keep up with your great ideas!" when their brainwaves showed that their attention was very concentrated (attention > 60, and lasted for 5 s).

The open-ended task required the participants to complete a challenging design task in 5 min. The task was to "design a wearable device that could replace or exceed the functionality of a smartphone, but the device could not be an Apple watch, which is already popular." During the entire design process, the brainwave status of the participant was recorded with attention value. Finally, after each of the participants completed the design activity and came out of the integrated virtual reality system, they filled out a flow state scale survey. All the works created by the participants in VR were evaluated of their creative performance levels by panel experts.

4.3. Instruments and scale validations

The Kaufman Domains of Creativity Scale (K-DOCS) was used as the baseline assessment of the participants' creative experience among different groups of individuals before every participant began the open-ended design task. The scale has 50 subdivisions and 5 broad areas: Everyday, Academic, Mechanical or Science, Artistic and Performance (including writing and music) (Kaufman, 2012). The Kaufman Domains of Creativity Scale ranges 0–5 on average. The reliability of K-DOCS is 0.8, which has proven to be effective and feasible. The scale has been widely used in creativity research in recent years (Ivcevic & Kaufman, 2013; McKay, Karwowski, & Kaufman, 2017).

Each of the participants' attention value was measured via the NeuroSky brainwave device. NeuroSky is a lightweight brainwave headset device. The eSense is a NeuroSky's proprietary algorithm for representing mental states. To calculate eSense, the NeuroSky Think Gear technology intensifies the raw brainwave signal and removes the ambient noise and muscle movement. The eSense algorithm is then applied to the remaining signal, resulting in explicated eSense meter values. The intensity of the "attention" of the brain can be presented, ranging from 0 to 100.

In order to compare the impacts of no feedback, reminder feedback and encouragement feedback on the flow state of different groups of individuals, we asked each participant to fill out the Flow State Scale immediately after each completed the design task in the integrated VR system. The FSS is a self-assessment that measured the participant's flow experience during the activity (Jackson & Marsh, 1996). The scales, which were proposed by Susan A. Jackson and Herbert W. Marsh, included nine dimensions of one's flow state described by: (1) clear goals, (2) challenge-skill balance, (3) unambiguous feedback, (4) concentration on the task at hand, (5) action-awareness merging, (6) transformation of time, (7) loss of self-consciousness, (8) sense of control, and (9) autotelic experience. The reliability of FSS scales in the nine dimensions and 36 items was at least 0.8 (Jackson & Marsh, 1996).

The creativity levels of all the products in the open-ended design task were evaluated by five researchers. Four criteria were used to assess the creative quality of the design product in the VR by the participants. They included: generation of novelty, elegance, creation and relevance/validity (Haller, Courvoisier, & Cropley, 2011). The average value was known as the individual product creative quality. Based on the four criteria of the scale, the panel of experts rated each creativity product using the 5 point-Likert scale. The inter-rater reliability was 0.65 ($p < 0.01$), indicating that the test has acceptable reliability.

5. Results

5.1. Analysis of attention measured by EEG

ANOVA was used to answer the first question, which is, "Are there any differences of brainwave states of attention between the individuals in different EEG feedback groups?" The results of the attention of the three groups of individuals are shown in Table 1.

According to the ANOVA result for attention ($F = 0.94$, $p > 0.05$, Cohen's $F = 0.18$), the average values for attention were 49.75, 53.10,50.65 for the group with no feedback, group with reminder

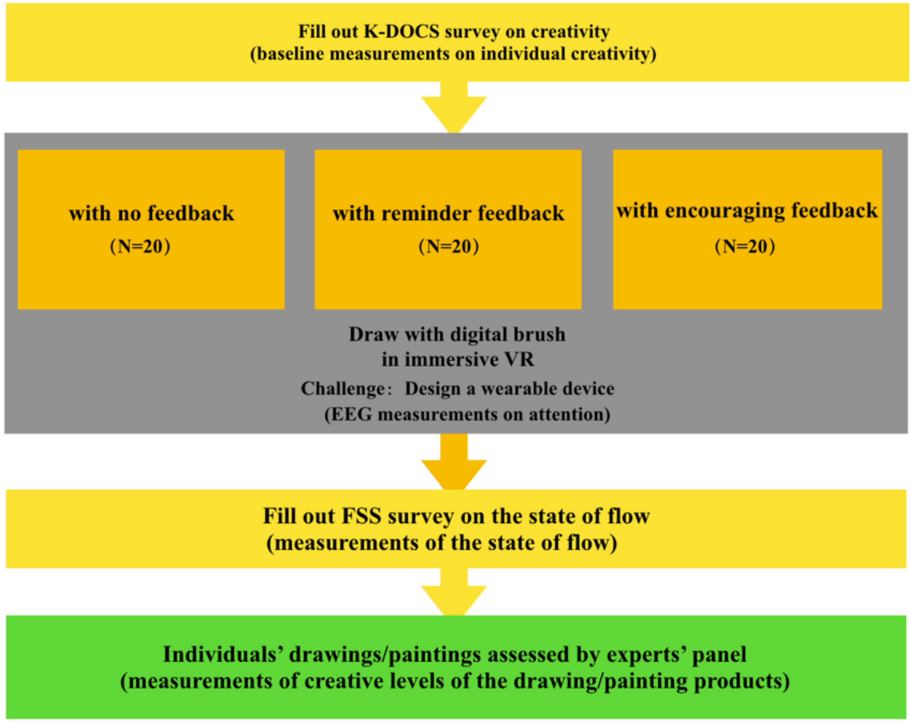

Fig. 3. The experimental process.

Table 1
ANOVA results of Attention in different feedback conditions.

Groups	N	Mean	SD	F
Individuals receiving no feedback	20	49.75	8.188	0.940
Individuals receiving reminder feedback	20	53.10	6.585	
Individuals receiving encouraging feedback	20	50.65	9.028	

feedback, and group with encouraging feedback, respectively. There was no significant difference in the attention value among the three groups ($p = 0.397 > 0.05$).

5.2. Analysis of the flow state

ANOVA was also used to answer the second research question, which is, " Which EEG feedback help the individuals get into the state of flow in the immersive virtual reality (VR) setting?" The ANOVA results of the flow state of the three groups are shown in Table 2.

There was a significant difference in the flow state between the three groups ($F = 3.278$; $p = 0.045 < 0.05$, Cohen's $F = 0.32$). For post hoc comparison, Table 2 also shows that the group with reminder feedback had a significantly higher flow state than the group with no feedback ($p < 0.05$) and the group with encouraging feedback ($p < 0.05$).

5.3. Analysis of individual product creative quality

Before analyzing the product creative quality of the three groups, we did a baseline analysis of the participants 'creative experiences using K-DOCS. The mean values of the level of creativity(K-DOCS)scores were 3.296 for the control group with no feedback, 3.505 for the group with reminder feedback, and 3.277 for the group with encouraging feedback. The ANOVA results found that there was no significant difference in the levels of creativity (K-DOCS) between the groups of participants with no feedback, reminder feedback, and encouraging feedback($F = 1.178$, $P > 0.05$). That is, the three groups of participants had equivalent levels of creativity before the design activities.

The third question we asked in the study was "Which EEG feedback contribute to an individual's creative performance in the immersive virtual reality environment? " The ANOVA results of the creative performance of the three groups are shown in Table 3.

According to the ANOVA result for individual product creative quality ($F = 3.296$, $p = 0.044 < 0.05$, Cohen's $F = 0.32$), the average ratings for "creative performance" were 3.22, 3.77, 3.52 for the group with no feedback, the group with reminder feedback, and the group with encouraging feedback, respectively. For post hoc comparison, the results showed that the participants with the reminder feedback condition produced a higher individual product creative quality level than the participants with the no feedback condition ($p < 0.05$).

6. Discussions

In this study, we aimed to explore the effects of providing feedback on the participants' attention, flow state, and creative performance in an immersive VR setting. We constructed different feedback mechanisms in the immersive VR setting, collected the attention data of the

Table 2
ANOVA results of flow state.

Groups	N	Mean	SD	F	Post hoc tests
Individuals receiving no feedback (a)	20	3.54	0.708	3.278[a]	b > a
Individuals receiving reminder feedback (b)	20	3.97	0.496		b > c
Individuals receiving encouraging feedback (c)	20	3.50	0.697		

[a] $p < .05$.

Table 3
ANOVA results of individual product creative quality.

Groups	N	Mean	SD	F	Post hoc tests
Individuals receiving no feedback (a)	20	3.22	0.551	3.296[a]	b > a
Individuals receiving reminder feedback (b)	20	3.77	0.669		
Individuals receiving encouraging feedback (c)	20	3.52	0.809		

[a] $p < .05$.

participants through brainwaves, and explored the effects of different feedback mechanisms on individual creative performance. The results showed that the participants who received reminder feedback had a higher attention value, significantly higher flow states, and higher quality creative product levels than those in the groups with no feedback or encouraging feedback.

We started the study asking if there would be different brainwave states of attention between the groups of individuals in different EEG feedback conditions. Each participant received an average of 3.4 feedback in the group with reminder feedback (N = 20). Each participant in the group with encouraging feedback (N = 20) received an average of 3.1 feedback. The provision of the audio feedback did not lead to a significant difference between the mean attention values among these groups. Previous studies have shown that giving feedback when there is a lack of focus or concentration helps learners to improve their attention in a reading or learning task significantly (Chen & Huang, 2014; Kuo et al., 2017; Lin et al., 2014). Studies have also shown that giving feedback can significantly increase the learner's attention level in textual knowledge learning activity (Sun & Yeh, 2017). In addition, previous studies show that encouraging feedback can increase the attention level during the task execution (Luft, 2014). This study did not find a significant difference of different feedback on attention levels. This finding is different from some previous studies, which showed that giving feedback when there was a lack of concentration helped the learners improve their attention in a reading or learning task significantly (Chen & Huang, 2014; Kuo et al., 2017; Lin et al., 2014). We suspect that there are several reasons for such differences. First, in the virtual reality environment, the overall levels of attention of the participants were relatively high regardless of feedback. Second, the participants' levels of attention in the open-ended design activities were also relatively high. Third, the entire design experiment process was only 5 min. As such, even though feedback had a positive impact on the individual's attention value, it did not reach a significant level in the remaining time given due to the short time frame and to the novelty effect of the setting. The finding from this study expands our understanding for the impact of feedback mechanisms on different types of activities.

We further wanted to find out if the two kinds of EEG feedback helped the individuals to get into the state of flow in the immersive virtual reality (VR) differently. The participants who received reminder feedback had significantly higher flow state levels than those in the group with no feedback or the group with encouraging feedback. Both forms of feedback in this experiment had an impact on the individual's flow state. In our study, the reminder feedback helped the participants to develop new ideas, while urging the participants to immerse themselves in the creative thinking process. Meanwhile, the encouraging feedback seemed to have interfered rather than helped when the participants were already highly concentrating on their tasks. The state of flow is closely related to attention (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2014). When the participants' concentration levels are high, this is often the time when the design work is being generated and focused. Giving encouraging feedback when attention is already highly concentrated may affect the state of immersion negatively and even interrupt the flow state.

Finally, we wanted to understand which of the EEG feedback better contributed to an individual's creative performance in an immersive virtual reality setting. The participants who received reminder feedback had significantly higher-quality creative products than those in the groups with no feedback or encouraging feedback. When the participants were not focused, they received the reminder feedback asking them to pay attention so that they would come up with good idea. This form of reminder feedback mechanism not only informed the participants to focus, but also urged the participants to think further about new ideas. The data showed that the participants came up with new ideas, added design details, added new creative features, or redesigned products after receiving the reminder feedback. Previous studies have shown that feedback contributes to self-regulation (Bandura, 1982). Good ideas are results of motivation at the right time (Duijnhouwer, Prins, & Stokking, 2012). Although the group of individuals who received encouraging feedback had a higher-level quality creative performance than those in the group with no feedback, the difference was not statistically significant. The voice of encouragement was a type of motivation, but it appeared that the encouraging feedback might have stopped some participants from trying harder. The data showed that some participants stopped creating new ideas; some even stopped working on the tasks, perhaps mistakenly thinking that they had successfully completed the tasks hearing the encouraging feedback. The timing of the encouragement feedback voice occurred at a time when the participant's attention was very concentrated. Consequently, this could have caused interference to the participant's creative thinking process. Previous studies have shown that attention-based feedback has a significant impact on the reading performance of the participants (Lin et al., 2014). Other studies have shown that this kind of feedback either had no significant impact on textual knowledge content (Sun & Yeh, 2017), or had no significant effect on the learning effect of procedural knowledge (Lin & Li, 2018). For the first time, our study attempted to examine this type of feedback in the creative activities in a virtual reality setting. This study expands the trial scope and application scenarios of the feedback mechanisms.

7. Limitations, suggestions for future research, and conclusion

There are several limitations of this study despite its theoretical and practical significances. First, this study took place in an immersive virtual reality environment, which had considerable advantages in collecting and capturing data more precisely. Yet, the novelty effect of the integrated VR system to perform a creative design on the participants cannot be ruled out (Adair, 1984). Such a novelty effect could have affected the results of the study. The study needs to be replicated to determine if the results would persist among similar or different populations. Second, this current research was limited to each participant performing a creative design in the VR setting for 5 min. It is arguable if a period of 5 min is sufficient to determine a person's attention, flow state, or creativity performance. However, the current technology limitations of VR and EEG settings would have made anything longer than 5 min too uncomfortable and too long for the participants (Beaty, Christensen, Benedek, Silvia, & Schacter, 2017; Fink & Benedek, 2014). Along this line, we were not able to collect or use the data from 15 out of 85 volunteering participants due to external and technical issues related to the brainwave devices and technologies. We do not believe this posed a threat to the internal validity of the research; still, we want to caution the generalization of our results. The rapid development of new technologies could help break through such limitations. Third, there are different statements of feedback that may have an emotional impact on the participants. In this study, the emotional responses of the participants were not evaluated or studied, and subsequent experiments could further study the impact of this aspect.

In summary, this study provided valuable insights for researchers, developers, and educators interested in helping students learn and create with effectively feedback. For researchers, the study sets a reference path for exploring the impact of feedback mechanisms on creativity performance. This path sets roots in the overlapping research areas of feedback, attention, flow and creativity theories. This study pioneers and helps promote further research in the feedback based on EEG brainwaves or in the immersive VR environments, and in facilitating creative designs.

For developers, the feedback strategy is a feedback mechanism that can be personalized, reducing the cost and improving the quality of feedback. This system can be applied to a large-scale personalized learning environment, with a continuously adjusted feedback strategy based on the status of each student. Data sources of feedback can be more diverse, not limited to attention, but using other kinds of brainwaves. The form of feedback can vary too, including, for instance, images, lights, vibrations and so forth (Moore, 2000).

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