INTERNATIONAL DESIGN CONFERENCE – DESIGN 2022
https://doi.org/10.1017/pds.2022.94

An Attempt to Grasp Resonance during Co-Creation with Biosignal Indicators

A. Matsumae ✉, K. Shoji and Y. Motomura
Kyushu University, Japan
✉ matsumae@design.kyushu-u.ac.jp

Abstract
Resonance is known as an important phenomenon where individual creative moments resonate with each other during co-creation. The purpose of this study is to capture this co-creative moment as a resonant cognitive status with biosignal indicators. The authors conducted an experiment in which pairs of participants work on concept generation from two nouns and measured their dynamic creative status both subjectively and objectively with biosignal indicators fEMG and EOG. This study will help to understand co-creative cognitive phenomena and to improve the co-creative design process.

Keywords: resonance, bio-signal, co-design, design cognition, idea generation

1. Introduction

During the design process, there is a moment of joy and the excitement of creation that is widely called the *creative moment* (Gonçalves *et al.*, 2013; Taura and Nagai, 2010). The creative moment is not only observed in individual design processes, but also in collaborative design. Collaborative designers empirically know the clear and essential difference in quality between them: a *resonance* includes something more than a set of individual creative states. The creative moment in collaborative design has been qualitatively discussed as a resonance in design studies (Nagai and Taura, 2017). Furthermore, Matsumae et al. focus on co-creative *subjectivity*, which is an unstable relationship and contrary to the cooperative one based on defined relationships. In other words, co-creative design cannot be sustainable without its wellbeing interpersonal relationships. It indicates that a co-creation with resonance forms and enhances interpersonal relationships, *intersubjectivity*, co-creative subjectivity. Intersubjectivity is that examinees do not constitute a world alone, but jointly with other examinees, which domain lies beneath the empathy (Bower, 2014; Zahavi, 2001), generates resonance and leads to the sustainable development of a co-creation phenomenon (Matsumae et al., 2020). A person who experiences a *resonant creative moment* is, at the very least, in a creative status, and, moreover, must feel he/she is sharing the creative process with another. There is a difference between simultaneous individual creative states and their resonant creative states, echoing the creative moment, has not been well-understood. Thus, the difference has been qualitatively discussed in collaborative design studies mainly from the perspective of *outcome*. A team marked by diversity but sharing a common similarity demonstrates greater team creativity than the sum of individual creativity. The greater range of ideas and members influencing each other stimulate creativity among collaborators and triggers new innovations (Hoever *et al.*, 2012).
The interest of this study is to grasp a resonance *quantitatively* with multimodal biosignal indicators as an interpersonal cognitive state during collaborative design which could enhance individual creativity and develop a co-creation phenomenon. The studies with EGG to grasp quantitatively interpersonal relationships (Motomura et al., 2015) and creative states (Li et al., 2021; Vieira et al., 2020) has been

very active in recent years. There have been recognized limitations of measuring creative states with EEG; it allows so limited movements to measure that its experimental protocol cannot represent the intended situation in appropriate scale; it is difficult to interpretate more than its measured activity. Therefore, the authors developed the methodology and attempted to grasp social relationship, intersubjectivity, as co-creative subjectivity with fEMG in previous study (Ehkirch *et al.*, 2021).
In this study, the authors focus on the cognitive differences between simultaneous individual creative moments and resonant creative moments, which could explain one of the essential differences between co-operative and co-creative design processes (Matsumae and Nagai, 2018). They attempt to grasp the subjectively clear cognitive differences with quantitative biosignal indicators fEMG and EOG.

2. Research methods

The authors conducted an experiment with pair concept generation, which can evoke resonance, and compared the quantitative and the qualitative data obtained to investigate resonant moments with biosignal indicators. Examinees were asked to work on a concept generation task in pairs. During the task, the examinees' fEMGs and EOG were recorded with a multi-modal sensor system, and their communications and drawings were recorded with video cameras. Immediately after the concept generation pair task, each of the examinees was asked individually to review their thinking process and their creative status (creative/non-creative, resonance) along with the video recorded during their concept generation. Correlations and similarities of data obtained were evaluated and compared with their creative status.

2.1. Experimental method

2.1.1. Examinees

In this experiment, the authors gathered examinees who were already familiar with collaborative concept generation, since it would be difficult to create resonance if they were not familiar with the experimental task itself. In all, 14 pairs of 28 undergraduate students in the third and the fourth year of the School of Design at Kyushu University participated in this experiment. Each of them confirmed in advance that they had experienced resonance during concept generation in collaborative design on a daily basis.

2.1.2. Experimental environment

The experiment was conducted in a laboratory at Ohashi Campus, Kyushu University, in November 2020. A clock was placed on the desk to show the time. Pens, colored pencils, and blank sheets of paper were provided for free and unlimited use. The experiment was recorded for review by four video cameras. One camera was set to record an overall view of the experiment, another camera was used to record their drawings on their working table, and each of the other two cameras was focused on each examinee's facial expressions.

2.1.3. Experimental procedure

After entering the room, examinees were told about the experimental procedure and fitted with electrodes for measurement. They practiced an icebreaking exercise for 20 minutes and individual concept generation for 15 minutes so that they could get accustomed to the experiment in advance, including the pair, the electrodes and the task. Then, they took a 10-minute break before they started concept generation work in pairs. The pair concept generation tasks were conducted for about 20 minutes. Immediately after pair concept generation, each of the examinees individually reviewed their pair work with recorded materials, video, and worksheets made during the pair concept generation work, and the examiner recorded each of their reviews on a common template (Figure 1).

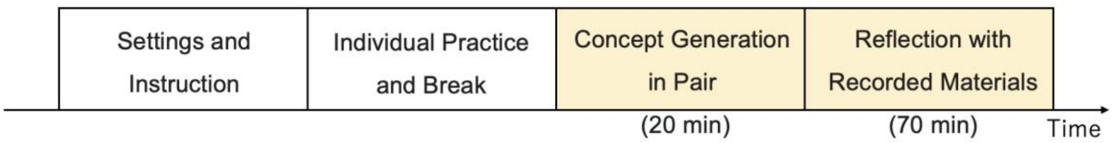

Figure 1. Experimental Procedure

https://doi.org/10.1017/pds.2022.94 Published online by Cambridge University Press

2.1.4. Experimental task

The examinees were asked to work in pairs on a concept generation task based on combinations of two different nouns. The creativity of conceptual combinations in this case was manifested in the diversity of interpretations and polysemous phrases that lead to more interpretations; noun-noun compounds generate more meanings on average than adjective-noun compounds, and those containing artifacts and superordinate concepts lead to significantly more interpretations. (Costello and Keane, 2000). With this in mind, the authors chose a combination of two polysemous nouns for this experiment, "weather" and "drawing tools," which contain artifacts and superordinate concepts (Figure 2). As all examinees in this study were students of design, the examiners focused on choosing nouns with similar conditions among them, considering their diverse design fields and knowledge levels.

Prior to starting the experiment, all participants were shown the same sets of concept generation examples created from "tomato" and "snow," following previous studies (Nagai *et al.*, 2009) to confirm their understanding of what they needed to do for their experimental task. Examinees were told that there would be no evaluations of their concepts; this was to avoid any inhibitions they might feel when generating their concepts.

Figure 2. Examples of concepts generated

2.1.5. Multimodal biosignal indicators

Zygomaticus major and orbicularis oculi muscles are known to increase their activity when pleasant emotions arise, with the orbicularis oculi in particular being sensitive to the intensity of pleasant emotions (Cacioppo et al., 1988). Cacioppo et al. also found that the depth of cognitive processing of language was related to the activity of the mentalis (Cacioppo and Petty, 1981). Eyeblink interval is also known and applied to measure cognitive functions such as mind-wandering, cognitive flexibility, and attention–functions (Kruis *et al.*, 2016)

Thus, by measuring multimodal biosignal indicators during concept generation in pairs, the authors examined the relations between each of the biosignal indicators and the examinees' cognitive or emotional status, and the relations between biosignal indicators of examinees in pairs, to better understand *resonance* with biosignal indicators. A multi-modal biosignal amplifier system (Polyam4/Japan Suntech Co., Ltd.) and measurement electrodes (fEMG x 6, ocular EMG x 2, body ground x 1) were used to simultaneously measure multi-modal signals.

- fEMG: Electromyogram of facial muscles (corrugator supercilii, orbicularis oculi, mentalis)
- vEOG: Electrooculogram of vertical eye movement to measure blinking

2.1.6. Subjective creative states and resonance

Each of the examinees was asked individually to record transitions in their creative state during the experimental task on a 5-level scale from -1 to 3 immediately after the experimental task was finished. They were instructed to try to fill it between 0 and 2 (0: non-creative state, 1: moderately creative state, 2: strongly creative state) and -1 or 3 only when they could not fit it in the range from 0 to 2. The examiner then interviewed each examinee to add the examinee's thinking processes to the record sheet

https://doi.org/10.1017/pds.2022.94 Published online by Cambridge University Press

corresponding to the transitions of creative states, reviewing the video recorded during the experiment at the same time to tag each of the states in an experimental timeline. The examinees were also asked to specify the timing of when they felt *resonance*.

2.2. Evaluation methodology

The authors analyzed the responsive relations during pair concept generation to better understand resonance with multimodal biosignal indicators by comparing the multimodal biosignal indicators and the transitions of recognized subjective states with or without resonance.

2.2.1. Subjective evaluation

For the subjective evaluations, the authors binarized the creative state into creative or non-creative states for each examinee based on the transition of the creative state, thinking process, and the recorded video . The threshold was set for each examinee to binarize the creative state based on their descriptions, with the creative state recorded above the threshold judged as creative and that below as non-creative. These binarized creative states were carefully reviewed with the examinee's description of his/her thinking process and the observed video. For instance, if the examinee explained the state as "I stopped thinking and I was absent of mind," the state was judged as non-creative even if the binarized data showed it to be creative.
Based on the individual subjective evaluation of the creative states above, the creative state in a pair was categorized into four categories: that where neither of the examinees in a pair was in a creative state (LL), that where one of the examinees in a pair was in a creative state (HL), that where both examinees in a pair were in a creative state (HH) and that where both pairs felt resonance (R). Figure 3 provides an example of the subjective evaluations used to describe creative states in a pair between examinee A and B.

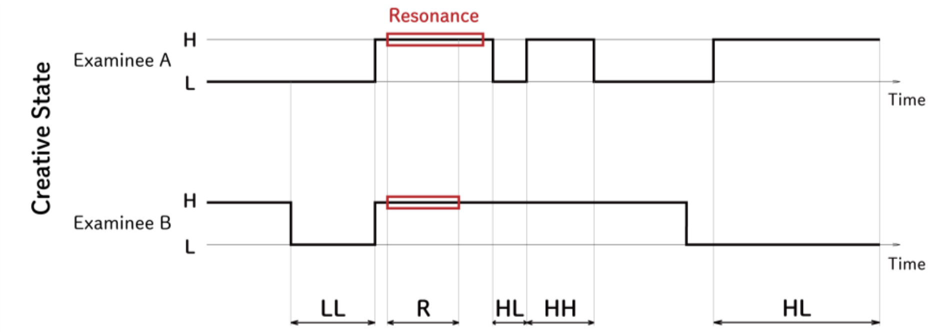

Figure 3. Subjective evaluation of creative states in a pair

The representative intervals for each creative state in each pair that have the clearest tendencies that can be analyzed were specified by the following criteria: HL, where the interval between degrees of creative states was the farthest between the two examinees; HH/LL, the interval where the degree of creative state was the highest/lowest; and R, the interval where resonance was most strongly felt. The datasets of pairs who did not have an interval where both examinees felt resonance were excluded from analysis.

2.2.2. Objective evaluation

The fEMGs (corrugator supercilii, orbicularis oculi, mentalis) and vEOG were measured at a sampling frequency of 1.0 kHz, and waveforms were obtained at 100 Hz by extracting every 10 data. Based on the subjective evaluation, the representative R, HH, and HL datasets were extracted. The fEMG datasets were rectified and transformed into rectified waves by ARV (Average Rectified Value) every 0.2 seconds, and the vEOG datasets were averaged every 0.05sec.

2.3. Analysis method

First, a normal Pearson correlation analysis was conducted between biosignal indicators and between examinees in a pair for fEMG datasets in each creative state to get an overview of the correlations. Second, the Levenshtein distance methodology was adopted to evaluate the similarity of waveforms between examinees in a pair for each biosignal indicator (Ehkirch *et al.*, 2021) and for each creative

https://doi.org/10.1017/pds.2022.94 Published online by Cambridge University Press

state, considering the chronological misalignment. The fEMG datasets were binarized with the median value of the rectified smoothing waveform to calculate Levenshtein distances. If the value exceeded the median value, it was replaced with "1" and, if not, with "0." The vEOG datasets were binarized with a threshold value of -50 μV. The Levenshtein distance is affected by the amount of data in the dataset because it is an edit distance throughout the dataset. This means that waveform similarities cannot be evaluated directly, whether between examinees or between creative states with different numbers of data. Therefore, Levenshtein distance per unit time was calculated to compare waveform similarities. A correspondent one-way ANOVA was applied to illuminate the differences in waveform similarities among creative states for each biosignal indicator, and where a significant difference ($p<0.05$) was obtained, the Tukey method was applied to test which creative states had a significant difference. Third, the authors conducted a corresponding one-way ANOVA between each creative state to compare the groups of individual means of ARV for fEMGs and the groups of individual averages of blink intervals for EOG in each creative state. When a significant difference ($p<0.05$) was found, a t-test with correspondence considering multiplicity was conducted, referring to the Bonferroni method, to test for a significant difference between any of the creative states.

3. Results and discussions

3.1. Correlation analysis

The following tables show the results of the correlation analysis of the rectified and smoothed waveforms of the fEMG. Table 1 shows the correlation coefficients between two specific fEMG biosignal indicators of creative state (LL, HL, HH, R) for each examinee, and Table 2 shows those between the individual datasets within a pair of specific fEMG biosignal indicators of creative state (LL, HL, HH, R). The correlation coefficients lower/higher than -0.4/0.4 are in bold (*p<0.05, **p<0.01).

Table 1. Correlation coefficients between biosignal indicators for each examinee

		corrugator supercilii and orbicularis oculi		corrugator supercilii and mentalis		orbicularis oculi and mentalis	
Creative State	Pair Number	Examinee A	Examinee B	Examinee A	Examinee B	Examinee A	Examinee B
LL	P1	**0.817****	**0.609****	0.013	0.145**	0.029	0.245**
	P2	**0.510****	**0.403****	-0.043	-0.006	0.063	0.063
	P3	**0.689****	**0.591****	0.146	0.216*	**0.445****	0.336**
	P4	**0.646****	0.356**	0.102	0.262**	0.038	0.326**
	P5	0.307**	**0.694****	0.000	0.102**	0.167**	0.174**
	P6	0.312**	0.299**	0.119**	0.047	-0.009	0.341**
HL	P1	0.242**	**0.638****	-0.021	0.015	0.011	0.324**
	P2	**0.419****	**0.411****	0.103	0.210**	0.283**	0.145**
	P3	**0.646****	**0.570****	-0.017	-0.023	-0.061*	0.071*
	P4	0.259**	**0.524****	0.165**	0.326**	0.144**	0.246**
	P5	0.351**	**0.746****	-0.183*	-0.192**	0.048	-0.090
	P6	**0.670****	**0.510****	0.093	-0.012	-0.071	0.247**
HH	P1	0.163**	**0.724****	-0.021	0.066	0.031	0.031
	P2	**0.552****	0.353**	0.035	0.216**	0.122**	0.032
	P3	**0.760****	**0.622****	-0.130	-0.024	-0.133	0.054
	P4	**0.738****	**0.457****	0.029	0.027	0.009	**0.421****
	P5	0.314**	**0.693****	0.003	0.008	0.049	0.162**
	P6	**0.658****	**0.593****	-0.054	0.325**	-0.103	**0.534****
R	P1	0.204*	0.392**	-0.246*	-0.175	-0.041	0.318**
	P2	**0.515****	**0.454****	0.003	0.319**	-0.067	0.079
	P3	**0.744****	**0.596****	-0.131	-0.038	-0.231**	0.120
	P4	-0.075	**0.467****	-0.105	**0.432****	-0.188*	**0.500****
	P5	0.237**	**0.773****	0.035	0.075*	0.130**	0.144**
	P6	0.369**	0.132**	0.206*	-0.035	0.301**	**0.474****

https://doi.org/10.1017/pds.2022.94 Published online by Cambridge University Press

Table 2. Correlation coefficients within each pair

Creative State	Pair Number	corrugator supercilii	orbicularis oculi	Mentalis
LL	P1	-0.023	0.031	0.118*
	P2	0.051	0.046	-0.010
	P3	0.048	-0.041	**-0.431****
	P4	**0.530****	0.166*	0.150*
	P5	0.142**	0.107**	0.022
	P6	0.112**	0.106**	0.058
HL	P1	0.084**	0.120**	-0.018
	P2	-0.069	0.064	0.117*
	P3	0.071*	0.180**	0.056
	P4	0.150**	0.081*	0.014
	P5	-0.024	-0.034	-0.069
	P6	0.086	0.103	-0.001
HH	P1	0.028	-0.009	0.046
	P2	0.043	0.000	0.043
	P3	0.001	0.100	0.069
	P4	0.215**	0.281**	0.186*
	P5	-0.003	0.079**	0.035
	P6	-0.078	-0.039	0.107
R	P1	-0.018	0.243*	-0.117
	P2	-0.002	-0.033	-0.177*
	P3	-0.080	-0.085	-0.075
	P4	-0.132	**0.634****	0.244**
	P5	-0.018	0.134**	-0.061*
	P6	-0.003	0.311**	0.165**

As seen in Table 1, correlations were commonly observed between the corrugator supercilii and the orbicularis oculi muscles. It is generally understood that the corrugator supercilii is correlated with negative emotions and the orbicularis oculi with positive emotions. On the other hand, both muscles are located around the eyes and are expected to become more active when the eyes are closed. Therefore, the basic correlation between the corrugator supercilii and the orbicularis oculi could be primarily caused by the fact that both muscles are located around the eye. When the examinees feel resonance, in creative state R, biosignal indicators show no clear tendency as to whether positive or negative correlations tend to increase when compared with other creative states. This overall result could reflect the deeper nature of resonance.

In Table 2, the correlations between examinees A and B in each pair tend to be stronger in creative states LL and R, and no correlation is found in HL (as expected), although the tendency is not sufficiently clear throughout the pairs. The authors have interpreted this result as an expected limitation of correlation analysis; correlation analysis cannot sufficiently cover the chronological misalignment of the waveforms. There should be a gap of time between examinees A and B in a pair when one transmits an idea to the other, especially considering an experimental task where two examinees develop their concept in turn based on mutual communication.

3.2. Levenshtein distance

Since the correlation tendency was examined by correlation analysis, the similarity of waveforms between examinees in a pair was evaluated with Levenshtein distance per unit time to consider biosignal indicators and the chronological misalignment of datasets between examinees in a pair. Figure 4 shows the Levenshtein distances per unit time for each creative state (LL, HL, HH, R) and each biosignal indicator; (a) fEMG for corrugator supercilii, (b) fEMG for orbicularis oculi, (c) fEMG for mentalis and (d) EOG.

https://doi.org/10.1017/pds.2022.94 Published online by Cambridge University Press

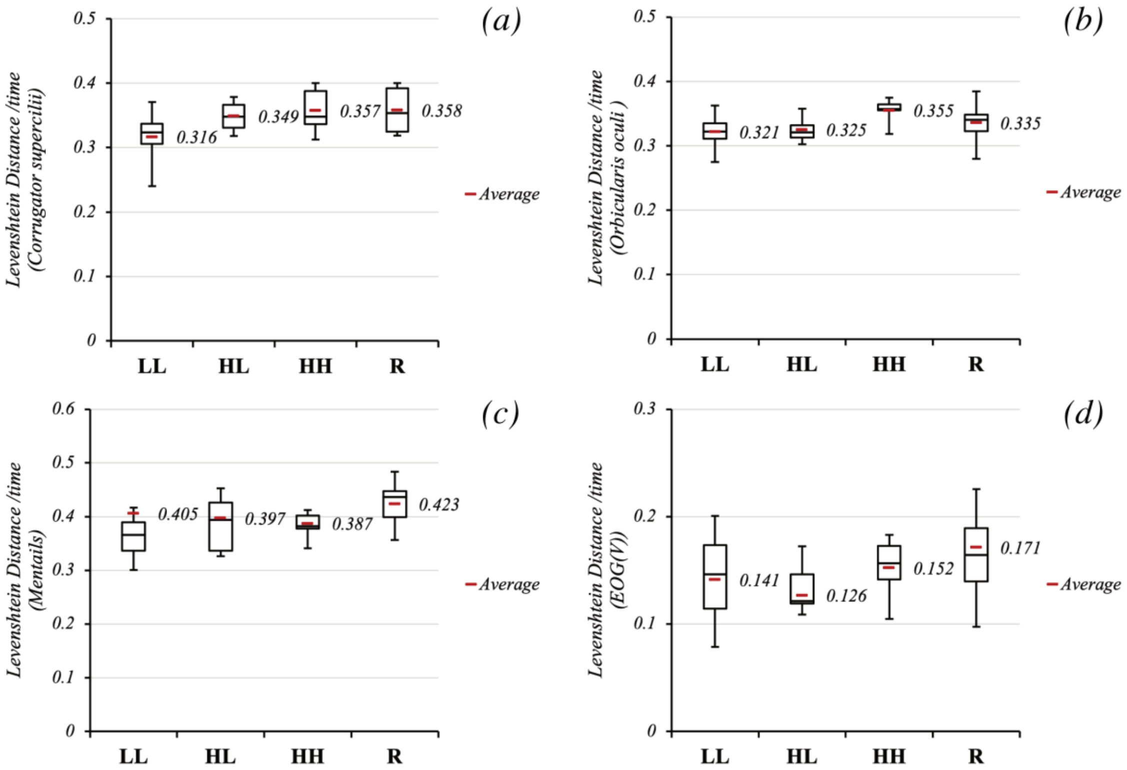

Figure 4. Similarity of waveforms between examinees in a pair

The authors conducted a one-way ANOVA with correspondence for each biosignal indicator and found a significant difference in EOG(V) ($p<0.05$). Multiple comparisons using the Tukey method were taken to examine the significant differences between the creative states, but none were found.

However, a tendency that could be expected from Figure 4(d) was that the greater the observed creative state, the more Levenshtein distances increased. In a previous study, it was reported that as *intersubjectivity* (the subjectivity of co-creation) is formed, the waveforms become more similar and the Levenshtein distance per unit time of fEMG for corrugator supercilii decreases (Ehkirch *et al.*, 2021). This suggests that resonance is not the convergent cognitive state during co-creation that intersubjectivity is. When they felt resonance, the examinees' reviews describing their experimental task also suggested that positive empathy was aroused toward the generated concept and synergistic idea development was observed. Therefore, resonance can be understood to be a divergent phenomenon, and Levenshtein distance of vEOG may grasp this divergent aspect of resonance. However, the tendency of Levenshtein distance to increase when waveforms themselves are active should be considered.

3.3. Activity assessment

Figure 5 indicates the amount of activity of each examinee for each creative state (LL, HH, and R) and each biosignal indicator; (a) fEMG for corrugator supercilii, (b) fEMG for orbicularis oculi, (c) fEMG for mentalis, evaluated by a median of the rectified smoothing waveform of fEMG. Figure 6 shows the mean blink intervals of individual examinees for each creative state (LL, HH, R) calculated from vEOG. The authors conducted a one-way ANOVA with correspondence for each biosignal indicator and found significant differences between all of the creative states in vEOG and in each fEMGs, for corrugator supercilii, orbicularis oculi and mentalis ($p<0.05$). They then executed a paired t-test for multiple comparisons using the Bonferroni method to examine significant differences between creative states. Significant differences were found between HH and R for corrugator supercilii and orbicularis oculi ($p<0.05$).

https://doi.org/10.1017/pds.2022.94 Published online by Cambridge University Press

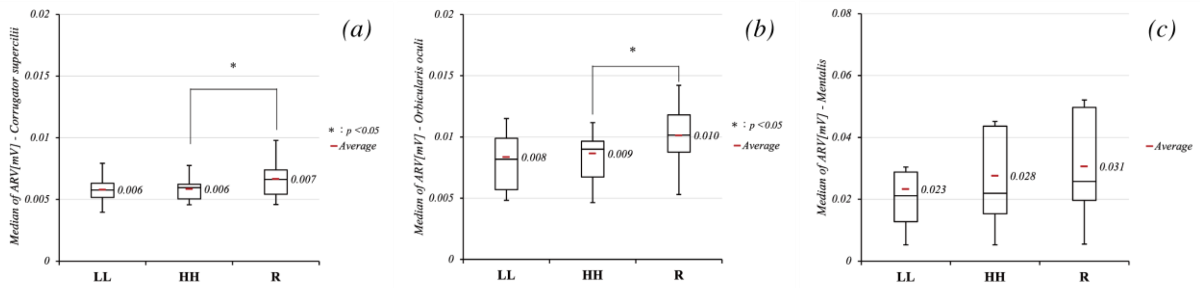

Figure 5. Activity fEMG activity

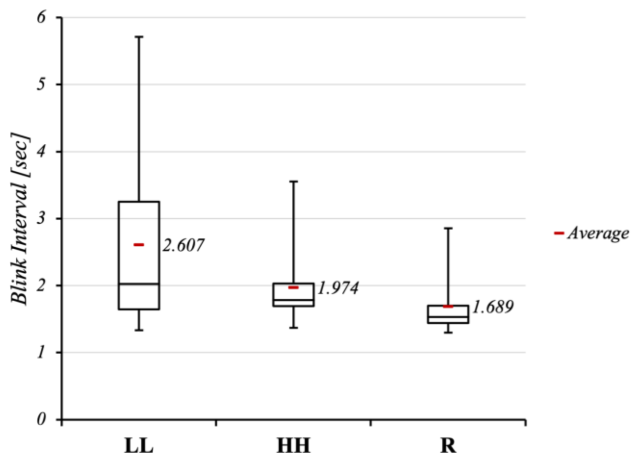

Figure 6. Blink interval

The insights obtained from these results are, first, that the activity of both the corrugator supercilii and orbicularis oculi increases when feeling resonance, and these fEMGs could be useful in understanding resonance. In general, though the orbicularis oculi is understood to be associated with positive emotions and the corrugator supercilii with negative emotions, however recent studies have shown that it is necessary to explore how such measures behave in richer context such as narrative ('t Hart *et al.*, 2018). Cacioppo et al also suggest that the depth of cognitive processing of language is related to the activity of the mentalis (Cacioppo and Petty, 1981). Blinking is also understood to become more frequent during focused thinking as opposed to unfocused thinking (Antrobus *et al.*, 1964).

Comparing the examinees' descriptions and idea development record sheets made during resonance, synergistic and responsive idea generations were observed after the arousal of positive sympathy. The corrugator supercilii and the orbicularis oculi could grasp these positive and active cognitive aspects of resonance. Second, blinking tends to be more frequent during resonance among creative states, and it may affect the increase in activity of both the corrugator supercilii and the orbicularis oculi, as they are muscles around the eyes.

Therefore, it could be suggested that *resonance* can be grasped with these biosignal indicators (vEOG and fEMGs for corrugator supercilii, orbicularis oculi and mentalis) reflecting positive and active cognitive aspects of resonance, although further experiments and analyses will be needed.

3.4. Levenshtein distance and activity

Due to its nature, the Levenshtein distance has a tendency to return a large value for active waveforms in general. The results of Levenshtein distance could be affected by the basic trends of the results of activity assessment per creative state (LL<HH<R). In other words, the similarities between waveforms could be undervalued for the resonant state (R) as opposed to the creative state (HH) and non-creative state (LL).

https://doi.org/10.1017/pds.2022.94 Published online by Cambridge University Press

4. Conclusion

In this study, the authors attempted to grasp *resonance*, which stimulates both individual creativity and co-creativity, experienced during concept generation in pairs with biosignal indicators (namely vEOG and fEMGs for corrugator supercilii, orbicularis oculi and mentalis). The significant differences between resonance (R) and a mere creative state (HH) were found in activity assessments with fEMG for corrugator supercilii and orbicularis oculi. Although no significant differences were found in this study, the authors expect that resonance could also be captured with EOG(V), which could reflect the active thinking and divergent aspects of *resonance* with the arousal of positive sympathy as blink intervals. Some indications for improvements in evaluation methodology were found and could be applied to future research as follows.

4.1. Limitations

The aim of this study was to gain an overview of a basic direction that can be used to grasp creative states and resonance with biosignal indicators, and whether a specific biosignal indicator can reflect resonance, as well as what kind of evaluation methodology can be useful in converting invisible subjective differences of creative states into visible differences. To this end, the authors focused on typical phenomena observed in each examinee, pair and creative state. An additional number of examinees and more overall and detailed analysis will be required to confirm the tendencies observed in this study, e.g. considering detailed qualitative differences within *resonance*.

4.2. Future research

The authors will conduct another experiment optimized in line with the basic tendencies suggested in this study. The evaluation methodology will also be improved and better focused by excluding the side-effects noted in this study. This study will contribute to enabling an external estimation of the invisible creative state and resonance during co-creation, and in further stages will provide a clue as to how certain interactions affect dynamic interpersonal creative states.

Ethical Statement

This study was approved by the Institutional Review Board of Kyushu University

Acknowledgement

This work was supported by JSPS Grant-in-Aid for Scientific Research JP20K20119.

References

Hart, B., Struiksma, M.E., van Boxtel, A. and van Berkum, J.J.A. (2018), “Emotion in stories: Facial EMG evidence for both mental simulation and moral evaluation”, *Frontiers in Psychology*, Vol. 9. https://doi.org/10.3389/fpsyg.2018.00613

Antrobus, J.S., Antrobus, J.S. and Singer, J.L. (1964), “EYE MOVEMENTS ACCOMPANYING DAYDREAMING, VISUAL IMAGERY, AND THOUGHT SUPPRESSION”, *J. Abnorm. Psychol.*, American Psychological association, Vol. 69, pp. 244–252. https://doi.org/10.1037/h0041846

Bower, M. (2014), “Developing open intersubjectivity: On the interpersonal shaping of experience”, *Phenomenology and the Cognitive Sciences*, Vol. 14 No. 3, pp. 455–474. https://doi.org/10.1007/s11097-014-9346-2

Cacioppo, J.T., Martzke, J.S., Petty, R.E. and Tassinary, L.G. (1988), “Specific forms of facial EMG response index emotions during an interview: From Darwin to the continuous flow hypothesis of affect-laden information processing”, *J. Pers. Soc. Psychol.*, psycnet.apa.org, Vol. 54 No. 4, pp. 592–604. https://doi.org/10.1037//0022-3514.54.4.592

Cacioppo, J.T. and Petty, R.E. (1981), “Electromyograms as measures of extent and affectivity of information processing”, *Am. Psychol.*, American Psychological Association, Vol. 36 No. 5, pp. 441–456. https://doi.org/10.1037/0003-066X.36.5.441

Costello, F.J. and Keane, M.T. (2000), “Efficient creativity: Constraint-guided conceptual combination”, *Cogn. Sci.*, Wiley Online Library. https://doi.org/10.1016/S0364-0213(00)00020-3

Ehkirch, Q., Kakiuchi, S., Motomura, Y., Matsumae, S. and Matsumae, A. (2021), “An Attempt to Understand Social Relationships Using Facial Expression Electromyography Analysis”, *Smart Innovation, Systems and Technologies*, Vol. 221, pp. 83–95. https://doi.org/10.1007/978-981-16-0041-8_8

Gonçalves, M., Cardoso, C. and Badke-Schaub, P. (2013), “Inspiration peak: exploring the semantic distance between design problem and textual inspirational stimuli”, *International Journal of Design Creativity and Innovation*, Vol. 1 No. 4, pp. 215–232. https://doi.org/10.1080/21650349.2013.799309

Hoever, I.J., van Knippenberg, D., van Ginkel, W.P. and Barkema, H.G. (2012), “Fostering team creativity: Perspective Taking as Key to Unlocking Diversity’s Potential”, *Journal of Applied Psychology*, Vol. 97 No. 5, pp. 982–996. https://doi.org/10.1037/a0029159

Kruis, A., Slagter, H.A., Bachhuber, D.R.W., Davidson, R.J. and Lutz, A. (2016), “Effects of Meditation Practice on Spontaneous Eye Blink Rate Ayla”, *Psychophysiology.*, Vol. 53 No. 5, pp. 749–758. https://doi.org/10.1111/psyp.12619

Li, S., Becattini, N. and Cascini, G. (2021), “Correlating Design Performance To Eeg Activation: Early Evidence From Experimental Data”, *Proceedings of the Design Society*, Vol. 1 No. AUGUST, pp. 771–780. https://doi.org/10.1017/pds.2021.77

Matsumae, A., Matsumae, S. and Nagai, Y. (2020), “Dynamic relationship design of knowledge co-creating cluster: traditional Japanese architectural industry”, *SN Applied Sciences*, Springer International Publishing, Vol. 2 No. 3, pp. 1–11. https://doi.org/10.1007/s42452-020-2209-2

Matsumae, A. and Nagai, Y. (2018), “The function of co-creation in dynamic mechanism of intersubjectivity formation among individuals”, *Proceedings of the DESIGN 2018 / 15th International Design Conference, Dubrovnik, Croatia, May 21-24*, 2018, The Design Society, Glasgow, pp. 1925–1936. https://doi.org/10.21278/idc.2018.0141

Motomura, Y., Takeshita, A., Egashira, Y., Nishimura, T., Kim, Y. kyu and Watanuki, S. (2015), “Inter-individual relationships in empathic traits and feedback-related fronto-central brain activity: An event-related potential study”, *Journal of Physiological Anthropology*, Vol. 34 No. 14, pp. 1–6. https://doi.org/10.1186/s40101-015-0053-7

Nagai, Y. and Taura, T. (2017), “Critical Issues of Advanced Design Thinking: Scheme of Synthesis, Realm of Out-Frame, Motive of Inner Sense, and Resonance to Future Society”, pp. 115–133. https://doi.org/10.1007/978-981-10-7524-7_8

Nagai, Y., Taura, T. and Mukai, F. (2009), “Role of Concept Blending and Dissimilarity in Creative Concept Generation Process: Comparisons between the Linguistic Interpretation Task and Design Task”, *Cognitive Studies*, Japanese Cognitive Science Society, Vol. 16 No. 2, pp. 209–230. https://doi.org/10.11225/jcss.16.209

Taura, T. and Nagai, Y. (2010), “Research Issues and Methodologies in Design Theoretics — From the Viewpoints of ‘Future’, ‘Ideal’ and “Composition”, *Cognitive Studies*, Vol. 17 No. 3, pp. 389–402. https://doi.org/10.11225/jcss.17.389

Vieira, S., Gero, J., Gattol, V., Delmoral, J., Li, S., Cascini, G. and Fernandes, A. (2020), “The Neurophysiological activations of novice and experienced professionals when designing and problem-solving”, *Proceedings of the Design Society: DESIGN Conference*, Vol. 1 No. June, pp. 1569–1578. https://doi.org/10.1017/dsd.2020.121

Zahavi, D. (2001), *Husserl and Transcendental Intersubjectivity*, Ohio University Press, Ohio.