CAA Proceedings

ACROSS THE HORIZON CAA 2024 Auckland Tāmaki Makaurau 8 - 12 April

# Analysis of Sensory Impression Factor Structures of Jomon Potteries through a Semantic Differential Method Viewing 3D Models on MR equipment

Haruhiro Fujita[1]*, Toru Miyao[2], Hiroyuki Sasaki[1], Hironori Imai[1],

Yew Kwang Hooi[3], Simon Kaner[4], Ryo Yamamoto[5], Kazutaka Kawano[5]

[1]Niigata University of International and Information Studies
[2]Niigata Prefectural History Museum
[3]University of Technology Petronas
[4]Sainsbury Institute for the Study of Japanese Arts and Cultures
[5]Tokyo National Museum
*Corresponding author: fujita@nuis.ac.jp

## Abstract

As Jomon pottery, particularly flame-like pot, is increasingly perceived as a form of artistic expression rather than merely archaeological artefacts by museum visitors, it is of interest to study the sensory impressions associated with it, and to investigate commonalities with the spatial cognitions that modern people have of Jomon pottery. A sensory impression test was conducted using 3D hologram models of pottery on Microsoft HoloLens with 73 participants, who rated 16 sensory adjectives through the Semantic Differential Method and also made free selections of impressive parts of the pottery. Factor analyses and analyses of variance were performed on these adjective groups, and identified main factors were "vigor," "attractiveness," "surface smoothness," and "lightness." The Okinohara and Umataka types consistently showed significantly higher scores on "vigor" (the first factor) and "attractiveness" (the second factor.) The correspondence of these two typological groups in sensory impressions and spatial cognitions suggests a shared commonality between them.

***Keywords***: sensory impression, Jomon potteries, Semantic Differential Method, factor analysis, analysis of variance, cognitive structures, spatial cognitions

**To cite this article:**
Fujita, H., Miyao, T., Sasaki, H., Imai, H., Hooi, Y.K., Kaner, S., Yamamoto, R., and Kawano, K. 2026. "Analysis of Sensory Impression Factor Structures of Jomon Potteries through a Semantic Differential Method Viewing 3D Models on MR equipment". In J. Emmitt & R. Phillipps (Eds.) Proceedings of the 51st Conference on Computer Applications and Quantitative Methods in Archaeology. *CAA Proceedings*, 51(1): Article 4:1-16 DOI: https://doi.org/10.64888/caaproceedings.v51i1.931

Submitted: 27/12/2025, Accepted 11/02/2026, First online 11/02/2026
Article preprint DOI: https://zenodo.org/records/15067200

## 1. Introduction

Mixed Reality (MR) refers to the technology that holographic models appear in the real space. Unlike virtual reality (VR), where the virtual space and visions are entirely constructed within the closed head-mounted display (HMD), in MR, holograms appear to be created in the actual environment by IR sensor's 3D measurement of the outer space, integrating 3D objects visible.

One of the research questions is whether cognitive structures and body perception can be measured using MR equipment, by employing verbal descriptors (adjective scales) and selections of impressive vessel parts. If these methods are unsuitable or insufficient for observing cognitive structures and body perception, what additional measures should be taken—such as recording participants' oral expressions of their impressions or using gaze tracking?

Another question is whether the perception and cognitive processes of modern people regarding Jomon earthenware of the target, dating approximately 5,000 years ago, are the same as those of the Jomon people.

The final question is whether, if we successfully extract parameters or data related to sensory impressions or cognitive processes using data science methods, it is possible to predict the cognitive structure through deep learning models, by statistical ways.

This is an introductive study focusing on participants' sensory impression structures of ancient artefacts, particularly middle Jomon pottery, using MR equipment. The study aims to gather basic information about participants' perception and cognitive responses before conducting a comprehensive study, which will attempt to represent cognitive processes through deep learning models by applying large amounts of material data and human cognitive response data, such as gaze heatmaps, using MR equipment. The obtained data can be used for the deep learning model development.

## 2. Literature review

### *2.1. Shinano River and the Jomon People*

The Shinano River, sourced from Mount Kobushigatake on the borders of Nagano, Saitama, and Yamanashi Prefectures, flows through the Saku Basin, Ueda Basin, and Nagano Basin as the Chikuma River in Nagano Prefecture. Upon merging with the Sai River in Nagano City, originating from Mount Yarigatake, it assumes the name Shinano River and continues to flow into the Sea of Japan at the border of Niigata Prefecture. As Japan's longest river, it spans a total length of 367 kilometers. The Jomon people, who settled in these basins 13,000 years ago, began producing pottery. Numerous archaeological sites from this period are densely concentrated in the upper reaches of the Shinano River basin (Shinano River Basin Kaen Root Cooperation Council 2021).

### *2.2. Emergence of Flame-like Pots in a Snowy Environment*

Approximately 8,000 years ago, a significant environmental change occurred with the advent of a warm current flowing into the Sea of Japan, leading to increased snowfall. This snowy environment persisted, and around 5,000 years ago, during the middle Jomon period, flame-like pots emerged. Characterized by designs and forms that evoke vigorous flames, flowing water, and waves, this pottery style is remarkably expressive. A distinctive feature of middle Jomon period potteries in the Shinano River basin are the presence of protrusions, most notably exemplified by flame-like pots adorned with four particularly bold protrusions, which represent a hallmark of the era (Shinano River Basin Kaen Root Cooperation Council 2021).

### *2.3. Spatial Cognition of the Jomon People and Potteries*

Archaeologist and anthropologist Kobayashi (1996) proposed spatial cognitive differences between the Jomon and modern people. He described houses as "rather holy container spaces," a concept perceived as such by the Jomon people.

Ishii (2010) further developed anthropological hypotheses on the spatial recognition of ancient Jomon people, defining cultural spaces during the Jomon period. He expanded upon Kobayashi Tatsuo's hypothesis, focusing on the "container nature" of space and analyzing the structure of spatial cognition and the symbolism of human-made spaces in the Jomon period, encompassing "houses," "villages," "monuments," and "earthenware" spaces.

Building on these hypotheses, Ishii suggested that Jomon potteries represent micro spaces reflecting the sensibilities and sensory impressions of the pottery makers.

### *2.4. Commonalities of Cognitive Processes and Mind Structures*

The work "Cognitive Archaeology, Body Cognition, and the Evolution of Visuospatial Perception" (Bruner 2023) illustrated how body perception and spatial sensing might have evolved in humans, suggesting that both body perception and spatial sensing share commonalities among all human beings .

Matsumoto (2000) employed the theory and methods of cognitive archaeology to argue that the mind and body have developed together over the course of human evolution. Therefore, the structure of the mind should be considered as universally common to the same extent as the structure of the human body. She also claimed that there is a certain degree of universality in human cognitive processes and cognitive structures, and that the same models and conceptual frameworks can be applied across cultural and social differences.

### *2.5. Quantitative Approach of Sensory Impression Factor Structure, Semantic Differential Method*

The Semantic Differential Method (SDM) is widely employed in psychology and the social sciences to examine participants' perceptions. This method assesses participants' attitudes and emotional responses toward specific concepts by utilizing bipolar adjective pairs (e.g., "beautiful–ugly," "strong–weak") on a 5- or 7-point rating scale. By capturing the connotative meaning of these concepts, the SDM offers a nuanced understanding of sensory impressions (Suzuki and Gyoba, 2003).

Thus SDM can be defined as a psychophysical testing approach used to extract human sensory perceptions or psychological images through participants' evaluations on scales with bipolar adjective pairs. This method has been widely employed to measure human sensory responses to various stimuli, including visual, auditory, gustatory, and textural elements.

Kawabata and Nagashima (1986) utilized the SDM to evaluate the taste and texture of three types of wild rice.

The Semantic Differential data consists of three modes: "participants," "scales," and "concepts" (Toyoda and Saito, 2005) . They developed positioning analysis methods to analyze multi-group three-mode data, as well as four-mode data.

Dai (1982) employed three-mode factor analysis to assess sensory perceptions of industrial chair designs.

Yamaguchi et al. (2004) explored the relationship between psychophysical and semantic characteristics of shapes by providing participants with stimuli comprising 32 geometric diagrams. These diagrams varied in magnitude along parameters corresponding to four psychological dimensions: curvedness, regularity, complexity, and openness/closedness, referred to as psychophysical features. Using the SDM, these shapes were evaluated, and factor analysis identified three factors: mildness, stability, and activity.

Semantic Differential data, typically comprising more than 20 bipolar adjective pairs, is commonly analyzed using factor analysis, as this method reduces dimensionality by identifying patterns within the adjective pair scores (Suzuki and Gyoba, 2003).

Factor analysis clusters related adjectives into underlying "factors" (e.g., happiness, attractiveness), facilitating interpretation by summarizing the data into fewer, meaningful dimensions. This approach is widely applied to extract core dimensions in studies of attitudes and perceptions (Wada et.al. 2003).

Flame-like pot appears to be perceived as a form of artistic expression rather than archaeological artefact by museum visitors. Therefore, studying the sensory impressions of participants regarding Jomon potteries, including flame-like pots, employing the SMD, is of significant interest.

## 3. Materials and methods

### *3.1. Hologram Preparation*

Eight Jomon potteries from the Middle Jomon Period, including two flame-like pots and a Sue ware from the Kofun Period, 6th century AD, shown as in Table 1, were optically scanned using the Go! Scan Spark scanner made by Creaform Inc. at a resolution of 0.5 mm. The scanner is equipped with three shape-tracking cameras, one colour camera, and one white light projector, which collectively generates mesh data containing colour and texture information via VXelements software. Subsequently, the mesh data with colour and texture information was exported in the OBJ (Wavefront Object) format. These nine pottery files were then downsized and the colour and texture maps were re-baked using Blender CG software for display on Microsoft HoloLens (Figure 1).

**Table 1: Potteries used for the experiment with sample IDs, typologies and make**

| NO. | SAMPLE ID | TYPOLOGY | MAKE |
|---|---|---|---|
| 1 | Okinohara-1 | Okinohara | Coil Building |
| 2 | Okinohara-2 | Okinohara | Coil Building |
| 3 | Umataka-flame1 | Umataka (flame-like pot) | Coil Building |
| 4 | Upper Ento | Upper Ento | Coil Building |
| 5 | Umataka-flame2 | Umataka (flame-like pot) | Coil Building |
| 6 | Umataka-crown1 | Umataka (crown-like pot) | Coil Building |
| 7 | Umataka-crown2 | Umataka (crown-like pot) | Coil Building |
| 8 | Katsusaka | Katsusaka | Coil Building |
| 9 | Sue ware | Sue Ⅱ-2 | Wheel Forming |

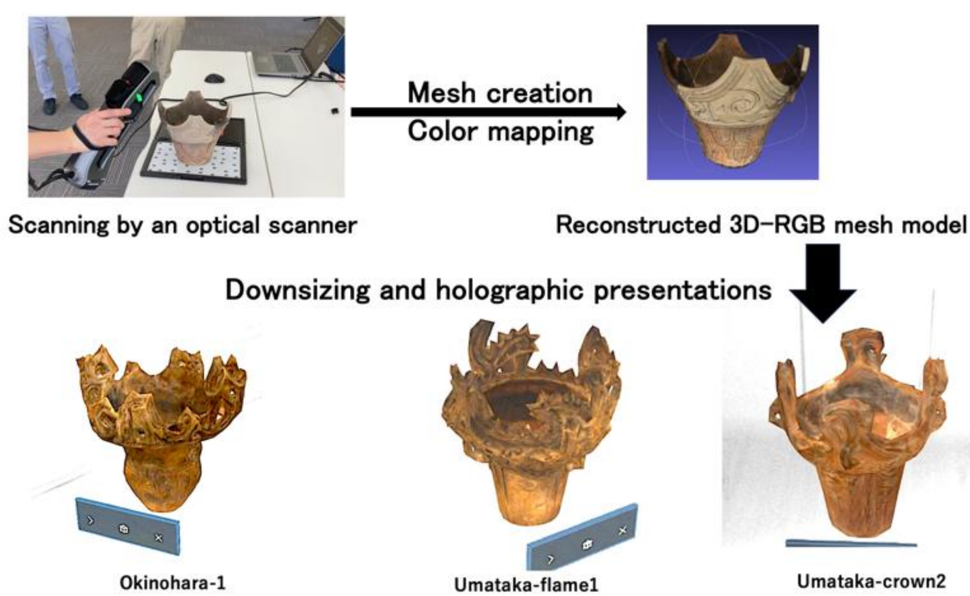


**Figure 1: Jomon pottery hologram processing**

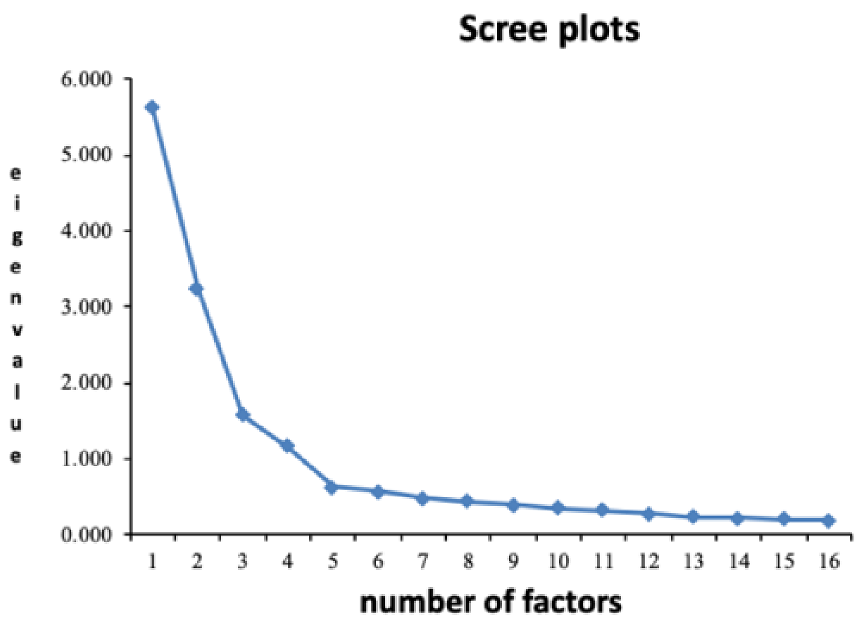


**Figure 2: Scree plots of Semantic Differential Method**

### *3.2. Sensory Impression Experiment and statistical analyses*

The experiment was conducted on July 11 and 13, 2023, in an experimental laboratory at Niigata University of International and Information Studies. Three Microsoft HoloLens devices were used. Visibility, with special attention to colour differences, was adjusted among those MR devices. Three parallel holographic exhibitions were set up, labelling 9 sample names in one line on the floor, and downloading hologram contents of potteries on top of those labels. Heights and sizes were adjusted manually. Thus, nine pottery items were arranged in three rows. Each HoloLens only displays holograms that have been downloaded.

The sensory impressions of the nine potteries were measured using the Semantic Differential Method. Sixteen adjectives were referenced and chosen from 20 adjectives in a study on sensory impressions of words and drawings (Suzuki and Gyoba, 2003)[6].

The 16 bipolar adjective pairs were as follows:

- beautiful-ugly
- pleasant-unpleasant
- likable-repugnant
- light-heavy
- cheerful-gloomy
- lively-quiet
- dynamic-static
- flashy-modest

- intense-calm
- powerful-feeble
- strong-weak
- soft-hard
- smooth-rough
- blunt-sharp
- relaxed-tense
- delicate-rugged

Five scale ranges from "very applicable" to "strongly not applicable," were set each adjective pairs, and 73 participants chose an applicable scale each adjective using Microsoft Forms questionnaire. The results were analyzed by HAD, a statistical macro script [12] using Factor Analysis with maximum likelihood extraction, Promax rotation (Power=4), and Kaiser normalization. Analysis of variance was then conducted on the mean factor scores of the nine pottery items to explain variations in impression factors.

On top of the Forms verbal adjectives questionnaire, a measurement of impressive partial selections was made. This asks the participants, after the series of adjective questions, the most impressive parts of the objects from the following: the rim of the vessel, the body of the vessel, the bottom of the vessel, the upper part of the vessel, the lower part of the vessel, the whole vessel, the inside of the vessel, or no particular part being impressive. Frequencies of the choices of the above were calculated and compared.

## 4. Results

The Scree plots are graphical presentations of factor variance plotted against the number of factors, used to determine the optimal number of factors before conducting factor analysis. Figure 2 depicts the Scree plots of the Semantic Differential (SD) method using 16 sensory impression adjectives. The lines show a sudden decrease at three factors, followed by four factors, both with eigenvalues exceeding 1.0. Therefore, three factors and four factors were selected for the factor analysis.

### *4.1. Factor Analysis with Three Factors*

The results are presented in Table 2. Three factor groups were derived from the sixteen adjective pairs based on factor load values greater than 0.448, as shown in Table 2.

The first factor (referred to as "Factor1") was labeled "vigor," encompassing adjectives such as "dynamic/static," "lively/quiet," "flashy/modest," "intense/calm," "cheerful/gloomy," "powerful/feeble," and "strong/weak."

The second factor was termed "attractiveness," representing adjectives like "beautiful/ugly" and "likable/repugnant."

The third factor was named "surface smoothness," capturing adjectives such as "smooth/rough," "relaxed/tense," "soft/hard," "blunt/sharp," "delicate/rugged," and "light/heavy.

### *4.2. Factor Analysis with Four Factors*

Table 3 presents the results of the four-factor analysis. The first factor was labeled "vigor," representing bipolar adjective pairs of "lively/quiet," "dynamic/static," "flashy/modest," "intense/calm," "cheerful/gloomy," and "powerful/feeble." The second factor was named "attractiveness," representing adjective pairs of "pleasant/unpleasant," "beautiful/ugly," and "likable/repugnant."

The third factor was termed "surface smoothness," encompassing bipolar adjective pairs of "blunt/sharp," "smooth/rough," "relaxed/tense," "soft/hard," and "delicate/rugged." The fourth factor was named "lightness," representing adjective pairs of "light/heavy" and "strong/weak (-6.65 correlation coefficient)."

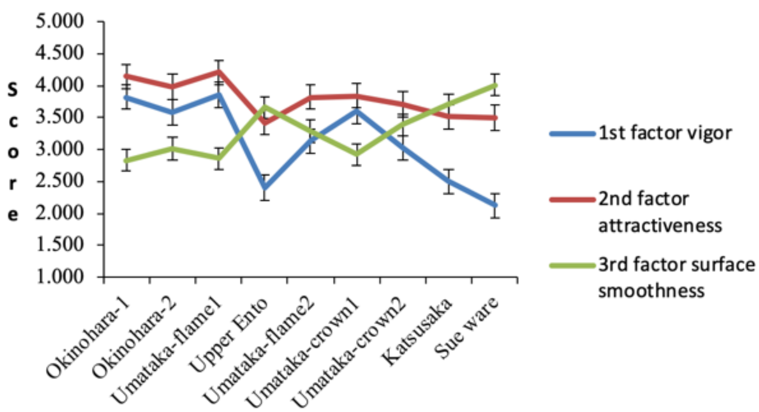


**Figure 3: Three Factor Score Variations in Potteries**

Table 4 Three Factor Score Variations in Potteries

| | | | | |
|---|---|---|---|---|
| Interaction P value | | .000 | ** | |
| | | | | |
| | 1st factor | 2nd factor | 3rd factor s | significance |
| Okinohara-1 | 3.820 | 4.146 | 2.831 | ** |
| Okinohara-2 | 3.587 | 3.986 | 3.016 | ** |
| Umataka-flame1 | 3.861 | 4.215 | 2.861 | ** |
| Upper Ento | 2.407 | 3.425 | 3.660 | ** |
| Umataka-flame2 | 3.139 | 3.822 | 3.292 | ** |
| Umataka-crown1 | 3.605 | 3.845 | 2.925 | ** |
| Umataka-crown2 | 3.027 | 3.712 | 3.384 | ** |
| Katsusaka | 2.507 | 3.516 | 3.708 | ** |
| Sue ware | 2.127 | 3.502 | 4.011 | ** |

Table 2 Factor analysis with three factors

samples = 657 variables = 16 factors = 3

extraction method = maximum likelihood
rotational method = promax rotation (Power = 4)
Kaiser normalization = Y

factor patterns

number of iterations = 6
convergence criterion = 0.0002

| | vigor | attractive ness | surface smoothness | |
|---|---|---|---|---|
| SD adjective pairs | Factor1 | Factor2 | Factor3 | Commonality |
| dynamic/static | **.932** | -.133 | .082 | .744 |
| lively/quiet | **.924** | -.120 | .117 | .726 |
| flashy/modest | **.879** | .012 | -.025 | .794 |
| intense/calm | **.833** | .006 | -.094 | .748 |
| cheerful/gloomy | **.645** | .110 | .205 | .468 |
| powerful/feeble | **.600** | .177 | -.114 | .529 |
| strong/week | **.579** | .165 | -.150 | .509 |
| pleasant/unpleasant | -.060 | **.915** | .052 | .805 |
| beantiful/ugly | .002 | **.841** | .010 | .710 |
| likable/repugnant | .143 | **.739** | .003 | .660 |
| smooth/rough | -.121 | -.030 | **.777** | .667 |
| relaxed/tense | -.061 | -.013 | **.713** | .533 |
| soft/hard | .226 | -.009 | **.683** | .435 |
| blunt/sharp | -.036 | -.040 | **.679** | .473 |
| deliate/rugged | -.100 | .251 | **.494** | .343 |
| light/heavy | .137 | .016 | **.448** | .192 |
| factor contributions | 5.054 | 3.219 | 2.885 | |

| fitness | | | | |
|---|---|---|---|---|
| | Deviation = | 0.829 | CFI = | .923 |
| | $\chi^2$ = | 537.062 | RMSEA = | .098 |
| | DF = | 75 | AIC = | 633.832 |
| | $p$ = | .000 | BIC = | 835.778 |

reliability coefficient *α and ω coefficients are calculated from items in bold (negative loads are reversed)

| | Factor1 | Factor2 | Factor3 |
|---|---|---|---|
| α coefficients | .918 | .880 | .792 |
| ω coefficients | .926 | .885 | .809 |
| factor scores | .937 | .896 | .835 |

Reliability coefficient when not reversed

| | | | |
|---|---|---|---|
| α coefficients | .918 | .880 | .792 |
| ω coefficients | .926 | .885 | .809 |

Inter-factor correlation

| | Factor1 | Factor2 | Factor3 |
|---|---|---|---|
| Factor1 | 1.000 | .437 | -.258 |
| Factor2 | .437 | 1.000 | .089 |
| Factor3 | -.258 | .089 | 1.000 |

Factor structure (correlation coefficients with factors)

| SD adjective pairs | Factor1 | Factor2 | Factor3 |
|---|---|---|---|
| dynamic/static | .853 | .281 | -.171 |
| lively/quiet | .841 | .294 | -.132 |
| flashy/modest | .891 | .394 | -.251 |
| intense/calm | .860 | .362 | -.309 |
| cheerful/gloomy | .640 | .410 | .048 |
| powerful/feeble | .707 | .430 | -.253 |
| strong/week | .690 | .405 | -.285 |
| pleasant/unpleasant | .326 | .893 | .149 |
| beantiful/ugly | .367 | .842 | .084 |
| likable/repugnant | .465 | .802 | .032 |
| smooth/rough | -.335 | -.014 | .805 |
| relaxed/tense | -.250 | .024 | .727 |
| soft/hard | .045 | .151 | .624 |
| blunt/sharp | -.229 | .004 | .685 |
| deliate/rugged | -.118 | .251 | .542 |
| light/heavy | .029 | .116 | .414 |

## Table 3 Factor analysis with four factors

samples = 657 variables = 16 factors = 4

extraction method = maximum likelihood
rotational method = promax rotation (Power = 4)
Kaiser normalization = Y

factor patterns

number of iterations = 5
convergence criterion = 0.001

| | vigor | attractive ness | surface smoothness | weight | |
|---|---|---|---|---|---|
| SD adjective pairs | Factor1 | Factor2 | Factor3 | Factor4 | Commonality |
| lively/quiet | **.955** | -.096 | -.016 | .190 | .761 |
| dynamic/static | **.947** | -.115 | -.024 | .125 | .757 |
| flashy/modest | **.857** | .018 | -.060 | -.021 | .784 |
| intense/calm | **.804** | -.014 | -.059 | -.148 | .760 |
| cheerful/gloomy | **.678** | .158 | .034 | .284 | .528 |
| powerful/feeble | **.527** | .105 | .096 | -.477 | .715 |
| pleasant/unpleasant | -.101 | **.934** | .031 | .019 | .799 |
| beantiful/ugly | -.039 | **.868** | -.019 | .024 | .712 |
| likable/repugnant | .111 | **.774** | -.050 | .058 | .668 |
| blunt/sharp | -.043 | -.105 | **.785** | -.110 | .573 |
| smooth/rough | -.111 | -.048 | **.749** | .100 | .667 |
| relaxed/tense | -.060 | -.042 | **.722** | .036 | .556 |
| soft/hard | .246 | .011 | **.558** | .238 | .430 |
| delicate/rugged | -.111 | .248 | **.472** | .059 | .342 |
| light/heavy | .221 | .103 | .167 | **.584** | .399 |
| strong/week | .504 | .086 | .073 | **-.509** | .715 |
| factor contributions | 5.060 | 3.371 | 2.738 | 1.929 | |

| fitness | | | | |
|---|---|---|---|---|
| | Deviation = | 0.223 | CFI = | .986 |
| | $\chi^2$ = | 144.445 | RMSEA = | .046 |
| | DF = | 62 | AIC = | 262.417 |
| | $p$ = | .000 | BIC = | 522.702 |

reliability coefficient *α and ω coefficients are calculated from items in bold (negative loads are reversed)

| | Factor1 | Factor2 | Factor3 | Factor4 |
|---|---|---|---|---|
| α coefficients | .912 | .880 | .809 | .358 |
| ω coefficients | .934 | .886 | .831 | .623 |
| factor scores | .936 | .898 | .834 | .622 |

Reliability coefficient when not reversed

| | Factor1 | Factor2 | Factor3 | Factor4 |
|---|---|---|---|---|
| α coefficients | .912 | .880 | .809 | -.557 |
| ω coefficients | .934 | .886 | .831 | .414 |

Inter-factor correlation

| | Factor1 | Factor2 | Factor3 | Factor4 |
|---|---|---|---|---|
| Factor1 | 1.000 | .478 | -.178 | -.325 |
| Factor2 | .478 | 1.000 | .139 | -.172 |
| Factor3 | -.178 | .139 | 1.000 | .318 |
| Factor4 | -.325 | -.172 | .318 | 1.000 |

Factor structure (correlation coefficients with factors)

| SD adjective pairs | Factor1 | Factor2 | Factor3 | Factor4 |
|---|---|---|---|---|
| lively/quiet | .850 | .326 | -.138 | -.109 |
| dynamic/static | .856 | .313 | -.168 | -.170 |
| flashy/modest | .883 | .423 | -.216 | -.322 |
| intense/calm | .856 | .388 | -.251 | -.426 |
| cheerful/gloomy | .655 | .438 | .026 | .047 |
| powerful/feeble | .715 | .452 | -.135 | -.636 |
| pleasant/unpleasant | .334 | .887 | .185 | -.099 |
| beantiful/ugly | .372 | .843 | .116 | -.120 |
| likable/repugnant | .471 | .810 | .056 | -.127 |
| blunt/sharp | -.197 | .003 | .743 | .172 |
| smooth/rough | -.300 | -.014 | .794 | .383 |
| relaxed/tense | -.220 | .023 | .739 | .293 |
| soft/hard | .074 | .165 | .592 | .334 |
| delicate/rugged | -.095 | .251 | .545 | .203 |
| light/heavy | .051 | .131 | .328 | .547 |
| strong/week | .698 | .425 | -.167 | -.665 |

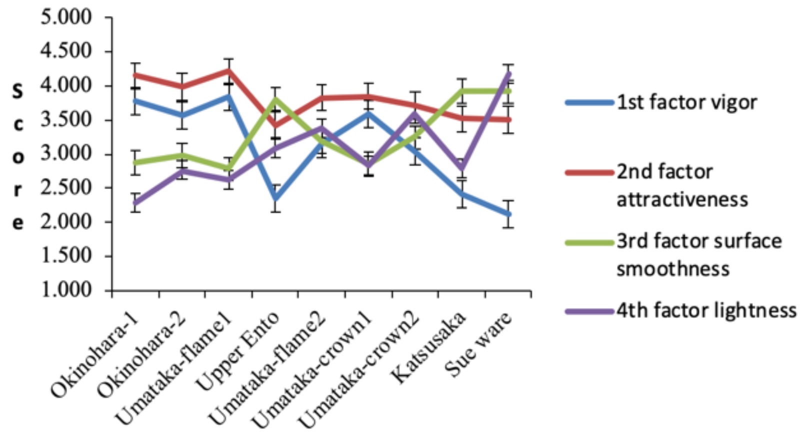


**Figure 4: Four Factor Score Variations in Potteries**

Table 5 Four Factor Score Variations in Potteries

| Interaction P value | .000 ** | | | | |
|---|---|---|---|---|---|
| | 1st factor | 2nd factor | 3rd factor | 4th factor | significance |
| Okinohara-1 | 3.781 | 4.146 | 2.874 | 2.281 | ** |
| Okinohara-2 | 3.575 | 3.986 | 2.984 | 2.760 | ** |
| Umataka-flame1 | 3.838 | 4.215 | 2.784 | 2.623 | ** |
| Upper Ento | 2.347 | 3.425 | 3.805 | 3.082 | ** |
| Umataka-flame2 | 3.153 | 3.822 | 3.186 | 3.384 | ** |
| Umataka-crown1 | 3.598 | 3.845 | 2.849 | 2.829 | ** |
| Umataka-crown2 | 3.050 | 3.712 | 3.244 | 3.596 | ** |
| Katsusaka | 2.418 | 3.516 | 3.923 | 2.795 | ** |
| Sue ware | 2.128 | 3.502 | 3.918 | 4.178 | ** |

**Table 6 Frequencies of impressed parts of vessels**

| | Okinohara -1 | Okinohara -2 | Umataka-flame 1 | Upper Ento | Umataka-flame 2 | Umataka-crown 1 | Umataka-crown 2 | Katsusaka | Sue ware |
|---|---|---|---|---|---|---|---|---|---|
| rim | 36 | 29 | 34 | 7 | 31 | 30 | 31 | 18 | 10 |
| upper part | 41 | 35 | 40 | 6 | 30 | 34 | 28 | 17 | 4 |
| lower part | 3 | 10 | 7 | 14 | 6 | 11 | 10 | 9 | 3 |
| bottom | 3 | 5 | 3 | 3 | 4 | 4 | 2 | 2 | 5 |
| whole vessel | 4 | 6 | 9 | 35 | 9 | 13 | 11 | 32 | 36 |
| inside vessel | 7 | 7 | 11 | 8 | 5 | 4 | 6 | 6 | 12 |
| not particular | 1 | 2 | 2 | 13 | 7 | 4 | 10 | 6 | 15 |

### *4.3. Analysis of Variance of Potteries on Three Factors*

Table 4 presents the factor score variations of the potteries, and Figure 3 illustrates the variations among potteries across three factors.

In terms of typologies, all Okinohara types (Okinohara-1and 2) and Umataka types (flame-1 and 2, crown-1 and 2) showed significantly higher scores for "vigor" (first factor) exceeding 3.0, and scores for "attractiveness" (second factor) exceeding 3.7.

On the other hand, Upper Ento, Katsusaka, and Sue ware exhibited significantly lower scores in the first factor. Figure 3 displays symmetric patterns between the first and third factors, "vigor" and "surface smoothness." Therefore, Upper Ento, Katsusaka, and Sue ware showed significantly higher scores in the third factor of “surface smoothness.”

### *4.4. Analysis of Variance of Potteries on Four Factors*

Table 5 presents the factor score variations of the potteries, and Figure 4 illustrates the variations among potteries across four factors.

All Okinohara types (Okinohara 1 and 2) and Umataka types (flame1 and 2, crown1 and 2) exhibited significantly higher scores for "vigor" (first factor) exceeding 3.0 and scores for "attractiveness" (second factor) exceeding 3.7 (consistent with the results of the analysis of variance on three factors). The factor scores of the first and the third factors displayed symmetric patterns, as found in the analysis of variance on three factors.

The factor scores for the fourth factor, "lightness," exhibited a different pattern compared to that of the third factor. The second highest score was observed in Umataka-crown2, followed by Sue ware, while the significantly lower score was observed in Katsusaka.

### *4.5. Comparison of Impressive Parts of Potteries*

Table 6 shows the frequency of pottery parts selected as impressive by the participants. Two distinct groups of potteries emerged based on the parts identified as impressive: the Okinohara and Umataka types were most frequently associated with impressive rims and upper sections, whereas the remaining three types were rated as highly impressive across the entire vessel.

## 5. Discussion

### *5.1. Sensory Impression Factor Structure*

The results indicated that both the Okinohara and Umataka pottery types (including two flame-like pots) yielded significantly higher impression structures of "vigor" and "attractiveness" compared to other Jomon pottery (Upper Ento and Katsusaka) and Sue ware. Conversely, the significantly lower scores of these six pottery types on the third factor suggested stronger impressions of "roughness" as opposed to "surface smoothness." The scores of these nine potteries exhibited a symmetric pattern between the first factor, "vigor," and the third factor, "surface smoothness." This study provides initial evidence of the prominent sensory impression characteristics of the Okinohara and Umataka types, which are chronologically and geographically close. They exhibited significant sensory impressions of greater "vigor" and "attractiveness," along with higher "surface roughness."

### *5.2. Correlation of Spatial Impressive Cognition and Sensory Impression Perceptions*

The typologies of impressive pottery parts showed strong correlations with the sensory impression factor structures. All Okinohara and Umataka types, which were noted for their impressive rims and upper parts, exhibited higher scores in the impression factors of "vigor" and "attractiveness." In contrast, the other three types—Upper Ento, Katsusaka, and Sue ware—were perceived as less vigorous and attractive.

### *5.3. Correspondence between Spatial Cognition and Sensory Impressions*

The finding that pottery groups sharing similar factor structures of sensory impressions also exhibit similar patterns in the parts identified as impressive suggests a strong correspondence between human sensory impressions and spatial cognition. This finding implies that individuals tend to form sensory impressions based on the areas of an object they find interesting. These areas capture the observer's attention through distinctive features, such as the rims of flame-like pots, prominent protrusions, or three-dimensional patterns. Conversely, when pottery lacks particularly striking elements, individuals may form a holistic impression of the object or focus less attention overall. This may explain why, in such cases, the entire piece of pottery is selected as a region of interest.

## 6. Conclusions

Jomon deep bowls were predominantly used for cooking purposes. However, the bold protrusions found in Okinohara and Umataka types, including flame-like pots, would have been impractical for inserting and removing food during cooking. This raises the possibility that these vessels were not primarily designed for culinary use, but rather as expressions of conceptual ideas influenced by the worldview of the Jomon people. Despite this assumption, most bowls with exaggerated protrusions show clear evidence of use in cooking, bottom remains of charred foods.

Among ancient pottery worldwide, such exaggerated protrusions are unique characteristic of pottery from the middle Jomon period, particularly from the Shinano River basin, where flame-like pots are prominent. This distinct feature makes them notable even on a global scale (Shinano River Basin Kaen Root Cooperation Council 2021).

### *6.1. Conclusions-Sensory Impression Structure*

The primary finding of this study is the significant prominence of "vigor" and "attractiveness" as key components in the sensory impression structure among participants who viewed holograms of four Umataka (flame-1 and 2, crown-1 and 2) pots and two Okinohara pots (Okinohara-1 and 2) using MR equipment. This result appears to be influenced by the remarkably expressive design, especially the four prominent protrusions characteristic of the pots.

In addition, this study contributes to advancing the understanding of the cognitive structure underlying sensory impressions of archaeological and cultural artefacts. It also underscores the potential of MR technology to enhance visitor engagement in museum settings.

### *6.2. Challenges in Cognitive Studies Employing Deep Learning Models*

Kulveit et al. (2023) and Constant et al. (2021) suggested that active Inference and the Large Language Models were key issues advancing neuroscience and cognitive science.

In future studies, sensory impressions of participants who observe Jomon pottery and anthropomorphic clay figures will be used to train a deep learning model embedded with 3D-RGB data of the objects, within the framework of a Large Language Model (LLM). When new 3D-RGB data of an artefact is input into the trained model, it reproduces gaze heatmaps and impression texts, which represent the "body perception and cognitive structure (Matsumoto 2020)."

Abstract thinking is considered one of the defining characteristics of modern humans, Homo sapiens (McBrearty and Brooks, 2000). The connection between object data and the abstract thinking of the mind—often referred to as the bridging point—is one of the most challenging aspects in advancing practical research.

Future studies will focus on methods to extract psychological insights from vast amounts of object data. When contemporary individuals view holograms of Jomon pottery and clay figures, sensory impressions are assessed using the Semantic Differential Method (SDM), linguistic expressions are analyzed by large language models (LLMs), and visual perceptions as gaze trajectory are recorded and analyzed by 3D convolutional-deconvolutional models (Miyao et al. 2023)(Chikayama et al. 2025)(Fujita et al. 2025). All cognitive and perceptual data are collected using a single mixed reality (MR) device.

A deep learning model designed to explore abstract thinking is employed to bridge the gap among multidimensional human perceptions, the cognitive structures underlying sensory impressions, verbal expressions, and physical objects. The integration of these multidimensional perceptions, impressions, and expressions with deep learning models remains a central focus of future research.

**Funding**

The authors acknowledge the Grants-in-Aid for Scientific Research (B), "Verification of Sueki pottery types and dating criteria by deep learning cluster analyses of 3D-RGB data," April 2022 - March 2025, and the "Challenge on data driven research foundation by merging typology and AI",

Grant-in-Aid for Challenging Research (Exploratory), January 2023 - March 2026, both funded by the Japan Society for the Promotion of Science.

**Conflicts of Interest**

The authors declare that they have no conflicts of interests relating to the content of this article.

**Author Contributions**

Conceptualization, H.F. and H. S.; methodology, H. F. and H. S.; software, H. S.; validation, H. F.; formal analysis, H. S.; pottery scanning, T. M.; Sue ware scanning, R. Y.; data curation, T. M. and R.Y.; writing—original draft preparation, H. F.; writing—review and editing, H. F.;

visualization, H. F.; supervision, H. F.; project administration, H. F.; funding acquisition, H. F.; participant experiment H. I.; English proof reading, S. K. and Y. K. H., Scientific supervision, K. K.

**Acknowledgements**

The authors acknowledge all 73 participants of experiment as well as research assistants who supported and conducted the HoloLens experiments. The authors also acknowledge the research ethic committee of the Niigata University of International and Information Studies for the research approval. The authors also extend their gratitude to Ayaka Nagumo and Kenta Ichikawa, BSN Inet Co., Ltd., for scanned artefact data archive and the multi angle image production as in Appendix A.

## References

Bruner E, (2023). Cognitive Archaeology, Body Cognition, and the Evolution of Visuospatial Perception. Elsevier Science & Technology, San Diego, UNITED STATES.

Chikayama E, T Nakada, T Miyao, and H Fujita (2025). Prototype of Point cloud-Captioning Model for Jomon Pottery. Proceedings of International Conference of Smart City-Volume 2, Lecture Notes in Electrical Engineering, 84-92, Springer Nature.

Constant A, A Daniel, D Tschantz, B Millidge, F Criado-Boado, L M Martinez, J Müeller and A Clark (2021). The Acquisition of Culturally Patterned Attention Styles Under Active Inference. Frontiers in Neurorobotics, Vol. 15, DOI: 10.3389/fnbot.2021.729665.

Dai K, (1982). Application of the Three-mode Factor Analysis to Industrial Design of Chair Styles. Japanese psychological review, Vol.25, No.1, 91-103.

Fujita H, A Nagumo, K Ichikawa, and YK Hooi (2025). Developments of AI Models from 1995 to 2024. Proceedings of International Conference of Smart City-Volume 2, Lecture Notes in Electrical Engineering, 71-83, Springer Nature.

Ishii T, (2010). "Spatial Recognition and Manufacturing in the Jomon Period." Research Bulletin of Kokugakuin Traditional Culture Research Center, Vol. 2, pp. 59-70.

Kawabata A, and N Nagashima (1986). Evaluation of Sensory Attributes of Wild Rice Using the Semantic Differentival Method. Journal of the Japanese Society of Food Science and Technology, Vol. 33, No. 2, 91-101.Shinano River Basin Kaen Root Cooperation Council (2021). Flame potteries in Shinano River Basin and Culture of Snow Country, a guidebook.

Kobayashi, T. (1996). "The World of the Jomon People." Asahi Sosho. Asahi Newspaper.

Kulveit J, C Stengel and R Leventov (2023). Predictive Minds: LLMs As Atypical Active Inference Agents. https://arxiv.org/abs/2311.10215.

Matsumoto N, (2000) Theory and practice of cognitive archaeology: The process of social and cultural changes from the Jomon to the Yayoi period, Kyushu University Press.

McBrearty S, and AS Brooks (2000). The revolution that wasn't: a new interpretation of the origin of modern human behavior. Journal of Human Evolution39, 453–563.

Miyao T, H Fujita, M Itagaki, K Ichikawa, A Nagumo, and K Kawano (2023). Voxel programing for 3D-RGB Jomon Potteries' deep learning cluster analyses and evaluation on 3D-data resolutions. 46th Conference Proceedings of Japan Society of Archaeological Informatics, 26 66-71.

Suzuki M, and J Gyoba (2003) Analyzing the factor structure and the sensory-relevance of impressions produced by words and drawings. The Japanese Journal of Psychology, Vol. 73, No. 6, 518-523.

Suzuki N, (2020). HAD statistical package. https://norimune.net/had

Toyoda H, and A Saito (2005). A Positioning Analysis Method for Three-Mode Multi-Group and Four-Mode Data in Semantic Differential Technique. The Japanese journal of educational psychology, 53, 414-426.

Wada Y, D Tsuzuki, T Yamaguchi, A Kimura, H Yamada, K Noguchi, and T Ooyama (2003). "Vision research using SD method -taking research on perceptual attributes and emotional effects as examples-", VISION Vol.15, No.3, 179-188.

Yamaguchi Y, J Wang and K Shiina (2004). The relationship between the psychophysical and semantic features of shapes. Japanese journal of cognitive psychology, Vol. 1, No.1, 45-54.