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Development of a Game Application Using Texture-Related Onomatopoeia With a Focus on Declined Texture Recognition in Dementia

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ABSTRACT

Texture recognition is an important component of everyday cognition, supporting the ability to infer material properties such as softness, roughness, smoothness, and slipperiness from visual information. Previous research has demonstrated that the visual texture recognition ability of patients with dementia is significantly lower than that of healthy individuals across various materials. These findings suggest that changes in texture recognition ability may serve as a useful indicator for the early detection of dementia. Our previous studies have shown that the Sound Symbolic Words Texture Recognition Test (SSWTRT) is a simple cognitive screening method that imposes a low burden on participants and is designed to evaluate cognitive decline using sound-symbolic words (SSWs). The objective of the present study was to develop an SSW-based game application that focuses on the decline in texture recognition ability associated with dementia and supports early screening through enjoyable interaction. We developed a two-phase game. The first phase consists of a falling-object collection task in which fruit items with different visual textures fall from the top of the screen, and players collect the items that match a target texture. The second phase consists of a sorting task in which players select the SSW that best matches each collected fruit from eight alternatives: fuwa-fuwa (fluffy), gotsu-gotsu (rugged), zara-zara (rough), tsuru-tsuru (smooth), sara-sara (dry/silky), sube-sube (sleek), deko-boko (uneven), and nuru-nuru (slimy). A scoring method was designed to evaluate responses in the sorting phase not simply as correct or incorrect, but according to the empirical distribution of SSW choices obtained from young, healthy participants in previous studies.

Keywords: Dementia screening, Texture recognition, Sound-symbolic words, Serious game

INTRODUCTION

Dementia is a clinical syndrome characterized by declines in cognitive functioning that interfere with everyday activities. The major cognitive domains affected by dementia include attention, memory, language, visuospatial processing, praxis, and executive function. These symptoms

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vary among individuals and may be influenced by physical, psychological, and environmental factors.

With the rapid aging of the global population, the early detection of cognitive decline has become an increasingly important public health priority. MCI (mild cognitive impairment) refers to a state of cognitive decline that is greater than expected for normal aging but does not substantially interfere with independence in daily activities. Individuals with MCI have a higher risk of developing dementia than cognitively healthy older adults; however, some individuals remain stable or return to a cognitively normal state. These characteristics highlight the importance of identifying subtle cognitive changes at an early stage and providing appropriate monitoring and intervention.

Several neuropsychological instruments are used to assess cognitive functioning. The Mini-Mental State Examination (MMSE) is one of the most widely used screening tools and assesses orientation, memory, attention, calculation, language, and visuoconstructive ability. Although commonly used tests are clinically valuable, they have several limitations as tools for frequent or large-scale screening. Some tests require administration and interpretation by trained professionals, and detailed neuropsychological assessment can be time-consuming. Test situations may also cause psychological discomfort because participants are explicitly required to demonstrate their memory, calculation, or linguistic abilities and may become aware of their mistakes. Moreover, the sensitivity of conventional tests may differ according to an individual's premorbid ability and the cognitive domains primarily affected. Therefore, complementary screening approaches that are brief, easy to administer, and less psychologically burdensome are needed.

One potentially informative but relatively underexplored indicator of cognitive decline is texture recognition. Visual texture recognition enables people to infer material properties such as softness, roughness, smoothness, wetness, and slipperiness without directly touching an object. This ability is important in everyday life. For example, visually recognizing that a floor is wet and slippery allows a person to adjust their movements and avoid falling. Texture recognition requires the integration of surface patterns, gloss, shading, color, and contextual visual information.

Previous studies have suggested that this ability can be impaired in people with dementia. Oishi et al. reported that patients with Alzheimer's disease or dementia with Lewy bodies had difficulty identifying material and surface properties from visual images (Oishi et al., 2018, 2020). In a vegetable-freshness judgment task, cognitive impairment was associated with reduced accuracy in selecting the fresher vegetable from two photographs. In another material-matching task, participants were shown a line drawing of an object and several material images and were asked to select the material appropriate for that object. Patients with dementia had difficulty selecting appropriate materials for many of the presented items. These findings indicate that changes in texture recognition may occur from relatively early stages of cognitive decline and may provide information that is not fully captured by conventional memory-centered tests.

To evaluate texture recognition in a simple and intuitive manner, our previous study developed the Sound Symbolic Words Texture Recognition Test (SSWTRT) (Kamohara et al., 2024). Sound-symbolic words, commonly referred to as onomatopoeia, express sensory, emotional, or dynamic impressions through systematic associations between speech sounds and meaning. Japanese has a particularly rich inventory of sound-symbolic words describing non-auditory sensations. For example, fuwa-fuwa expresses a soft and fluffy impression, zara-zara expresses a rough or coarse surface, and tsuru-tsuru expresses a smooth and often glossy surface.

Sound-symbolic words may be particularly suitable for communicating texture impressions because they express multidimensional sensory qualities in a concise and intuitive form. They may also be relatively robust to certain types of language impairment. Previous research has reported that individuals with aphasia can retain the ability to produce or understand sound-symbolic expressions even when their production of other words is substantially reduced (Hashimoto et al., 2014). Thus, the use of sound-symbolic words may reduce the linguistic burden associated with verbally describing subtle material properties.

In the SSWTRT, participants view 12 close-up photographs of material surfaces and select, for each image, the most appropriate expression from eight Japanese sound-symbolic words: fuwa-fuwa (fluffy), gotsu-gotsu (rugged or hard), zara-zara (rough), tsuru-tsuru (smooth and glossy), sara-sara (dry or silky), sube-sube (sleek or pleasantly smooth), deko-boko (uneven), and nuru-nuru (slimy). The test can be completed within a relatively short period and does not require the participant to memorize word lists or solve arithmetic problems.

An important characteristic of the SSWTRT is that responses are not scored using a single objectively correct answer. Texture impressions can vary across individuals, particularly for visually ambiguous materials. Therefore, each response is scored according to the empirical distribution of sound-symbolic-word choices obtained from healthy young participants. A response frequently selected by the reference group receives a higher score, whereas a rarely selected response receives a lower score. This probabilistic scoring approach preserves the graded nature of texture perception rather than treating every response as simply correct or incorrect.

Our initial study involving patients with idiopathic normal-pressure hydrocephalus showed that SSWTRT scores were moderately associated with established neuropsychological measures, including the MMSE and tests of verbal memory and executive function (Kamohara et al., 2024). The SSWTRT scores also differed significantly between participants with relatively preserved MMSE scores and those with possible mild cognitive impairment. These findings suggest that the test reflects not only visual texture processing but also broader cognitive functions involved in integrating visual information, retrieving sensory concepts, and selecting verbal expressions.

In a subsequent study, we investigated whether individual response patterns in the SSWTRT could be used to identify possible cognitive decline through machine learning (Nozaki et al., 2025). Rather than relying only on the total

test score, the model used the scores for individual texture images together with age and education. Among the evaluated classifiers, a support vector machine with class-balancing procedures achieved an accuracy and an area under the receiver operating characteristic curve of approximately 0.72. The analysis also showed that responses to particular images, especially those depicting soft or coarse textures, contributed strongly to the classification. These results indicate that patterns of texture-related sound-symbolic-word selection may contain information relevant to cognitive screening.

Despite these advantages, the original SSWTRT is presented explicitly as a cognitive assessment. Some older adults may hesitate to participate in such assessments because of anxiety about poor performance or the possibility of being judged as cognitively impaired. One approach to reducing this psychological barrier is to embed the assessment task within a digital game. Serious games have been used to support cognitive stimulation, rehabilitation, and training in older adults. Compared with repetitive conventional exercises, games can provide immediate feedback, clear goals, adjustable difficulty, and enjoyable interaction. Few games have focused on visual texture recognition or have used sound-symbolic words as an interface for assessing sensory–cognitive processing.

The design of digital games for older adults must also account for age-related changes in vision, touch, and motor control. Small targets, low-contrast color combinations, complicated gestures, and rapid time limits can unnecessarily increase task difficulty. Older users may also be less familiar with swiping, dragging, or other touchscreen operations. Accordingly, a game intended for cognitive screening should employ simple interactions, clearly visible objects, sufficient contrast, understandable instructions, and a difficulty level that does not produce excessive frustration.

In the present study, we developed a sound-symbolic-word-based (hereafter onomatopoeia-based) game application that incorporates the basic concept of the SSWTRT into an enjoyable two-phase interaction. In the first phase, fruit objects with different visual textures fall from the top of the screen, and the player collects objects matching a target texture. In the second phase, the player sorts the collected fruit by selecting the sound-symbolic word that best represents its texture. The responses are evaluated using the empirical response distributions obtained from healthy participants, following the probabilistic scoring principle of the SSWTRT.

This study represents an initial step toward transforming a brief texture-recognition assessment into a more engaging digital experience. The primary contribution is the design of a game that combines visual texture discrimination, sound-symbolic-word selection, and distribution-based scoring. By embedding these components in an accessible game format, we aim to establish a foundation for low-burden cognitive screening and repeated assessment that older adults can undertake with less anxiety. The present paper describes the design and implementation of the proposed game and examines its usability and potential as a game-based cognitive screening approach.

GAME DESIGN AND DEVELOPMENT

We developed a browser-based game application titled "Onomatore", designed primarily for use on smartphones. The game combines a falling-object collection task with a texture-sorting task using Japanese sound-symbolic words. The application was designed to provide an enjoyable and intuitive interaction while incorporating the fundamental procedure of the Sound Symbolic Words Texture Recognition Test (SSWTRT).

A falling-object game format was selected because its basic interaction is simple and easy to understand. Falling-object games have been played by a wide range of age groups for many years and are therefore likely to be familiar to older adults as well as younger users. Their simple rules and immediate visual feedback also make them suitable for short, repeated play sessions.

A falling-object game format was selected because its basic rules and operations are intuitive and familiar to a wide range of age groups. Long-standing games such as Tetris and Puyo Puyo, as well as more recent fruit-themed falling-object games, demonstrate that this genre can be enjoyed across generations. Moreover, adjustable speed, visual contrast, and object shape can be incorporated to accommodate differences in visual perception and motor ability.

More recently, fruit-themed falling-object games have attracted younger players because of their simple interaction and visually appealing design. Based on these characteristics, we considered a falling-object format suitable for a game intended to be approachable across generations. In the proposed game, fruits falling from a tree are collected and subsequently classified according to their visual textures.

The game consists of two consecutive phases: a falling-object collection phase and a texture-sorting phase. Each fruit item is presented with a particular visual texture. After collecting the fruits, the player evaluates their textures by selecting appropriate sound-symbolic words. The sorting phase was designed as a game-based implementation of the texture-recognition procedure used in the SSWTRT and may provide information relevant to cognitive screening.

The fruit and texture images used in the game were created by combining base fruit images with texture images. Generative AI was used as part of the image-creation process. The game system was designed so that item images can be replaced or added without modifying the overall game structure. This enables future studies to examine different visual materials and texture categories.

Because older adults are included among the intended users, the application provides adjustable settings for image size, falling speed, and object presentation frequency. These settings were introduced to reduce the influence of age-related differences in visual and motor function and to provide an interaction environment that can be adapted to individual users.

Falling-Object Collection Phase

In the falling-object collection phase, fruits with different visual textures appear at the top of the screen and fall at regular intervals. The player moves a basket horizontally along the bottom of the screen by dragging it to the left or right. The objective is to collect as many appropriate fruits as possible within a fixed time limit.

Before the phase begins, the player is shown a target texture. Fruits whose textures correspond to the target texture yield more points than other fruits. Additional points are awarded when the player collects multiple fruits consecutively, thereby producing a combo bonus.

In addition to fruits, insect objects may occasionally fall from the top of the screen. If the player collects an insect, one life is lost. This element was introduced to encourage visual attention and discrimination between target and non-target objects.

To make the textures of falling objects easier to perceive, object motion is controlled in a stepwise manner rather than through rapid continuous movement. The falling speed, object presentation interval, object size, game duration, and other parameters can be adjusted. These settings allow the task difficulty to be modified according to the age, visual ability, and operating ability of the player. The score obtained in this phase is referred to as the collection score.

Texture-Sorting Phase

After the collection phase, the player proceeds to the texture-sorting phase. In this phase, the fruits collected during the preceding task are presented individually.

For each fruit, the player selects the sound-symbolic word that best represents its perceived texture from the following eight alternatives:

fuwa-fuwa (fluffy),
gotsu-gotsu (rugged),
zara-zara (rough),
tsuru-tsuru (smooth and glossy),
sara-sara (dry or silky),
sube-sube (sleek or pleasantly smooth),
deko-boko (uneven), and
nuru-nuru (slimy).

The player can enlarge the presented image to inspect its visual texture in greater detail. This function was included to reduce difficulties caused by the relatively small display size of smartphones and by individual differences in visual ability.

The responses are not evaluated using a simple correct-or-incorrect criterion because visual texture impressions can vary among individuals. Instead, a score is assigned to each combination of image and sound-symbolic word based on the empirical response distributions obtained from healthy young participants in our previous studies. A response that was frequently selected for a given image in the reference data receives a higher score, whereas a less frequently selected response receives a lower score.

This distribution-based scoring method was adopted to preserve the graded and subjective nature of texture perception. It also enables the game to evaluate how closely a player's response pattern corresponds to the typical response pattern observed in the reference population. The score obtained in this phase is referred to as the texture-sorting score.

Final Score

The final game score is calculated by combining the collection score from the falling-object phase and the texture-sorting score from the sorting phase. The collection score primarily reflects game performance, including object detection, basket control, and sustained attention. In contrast, the texture-sorting score reflects the player's judgments of visual texture expressed through sound-symbolic words. Because these two scores represent different aspects of performance, they can also be recorded and analyzed separately. In particular, the texture-sorting score and the pattern of selected sound-symbolic words are treated as the primary measures relevant to the cognitive-screening function of the game, whereas the collection score is mainly used to maintain engagement.



Title page Falling-Object Collection Phase Texture-Sorting

Figure 1: Game flow of "Onomatore".

Construction of Textured Game Items

The textured game items were generated using ChatGPT and DALL·E 3. ChatGPT was used to interpret texture-related sound-symbolic expressions and to formulate image-generation instructions, whereas DALL·E 3 was used to synthesize the corresponding images. This combination enabled qualitative sensory expressions, such as softness, roughness, and slipperiness, to be translated into explicit visual-generation constraints.

Eight types of fruit that grow on trees were selected as the base objects to maintain consistency with the visual theme of the game. Two source images were prepared for each generation task: a base fruit image and a reference texture image. The base fruit images were generated with DALL·E 3 through ChatGPT. The reference set comprised 12 texture

images selected in our previous study, each of which had an empirically established distribution of responses across the eight sound-symbolic-word categories used in the SSWTRT. To generate a textured fruit item, the base fruit image and one reference texture image were provided simultaneously. The model was instructed to preserve the fruit's identity, overall shape, and original color while modifying only the appearance of its surface. The texture was also required to be applied uniformly across the visible fruit surface so that differences among items primarily reflected the intended texture rather than changes in object shape or color. The following prompt template was used:

Apply the texture shown in the second image to the fruit shown in the first image.

Please satisfy the following requirements:

- Apply a "fuwa-fuwa" texture.
- Preserve the original shape and color of the fruit, and modify only its surface texture so that it resembles the reference texture image.
- Apply the texture uniformly across the entire surface of the fruit.

The sound-symbolic word specified in the first requirement was replaced according to the target texture assigned to each item. The resulting images were used in both the falling-object collection phase and the subsequent texture-sorting phase. Responses in the sorting phase were scored using reference data obtained from healthy young participants in a previous study. For each texture image, the most frequently selected sound-symbolic word in the reference group was assigned a score of 100, and the remaining alternatives were assigned values from 0 to 100 in proportion to their selection frequencies. Thus, the method did not assume a single objectively correct verbal label for each texture. Instead, it quantified the degree to which a player's judgement agreed with the empirical response distribution of the reference population.

EVALUATION EXPERIMENT

An evaluation experiment was conducted with 12 adults aged 20 years or older. Of the participants, 10 were male and 2 were female, and their ages ranged from 22 to 25 years. Regarding their usual gaming habits, three participants reported that they "never play games," two reported playing "up to 5 hours per week," three reported playing "up to 10 hours per week," and four reported playing "more than 10 hours per week."

The participants played the developed game on a smartphone and subsequently evaluated it. Their responses were collected using a web-based questionnaire. This experiment was conducted with the approval of the Research Ethics Committee of our university (Approval No. H25084).

At the beginning of the experiment, the participants were provided with a tutorial explaining how to operate the game and how the game system worked. They then played the game five times and completed the web-based

questionnaire. The questionnaire mainly consisted of items assessing the game's usability, difficulty, and the participants' impressions of the texture items using a five-point Likert scale. The items are shown as follows:

- Were you able to participate in the experiment in a relaxed manner?
- Were the colors used in the game easy to see?
- Were the images used in the game easy to see?
- Were you able to operate the game intuitively?
- Was the in-game tutorial (game instructions) easy to understand?
- Was it clear what you were supposed to do in the game?
- Was the design of the game interface easy to understand?
- Was the game interface easy to use?
- Was the game system easy to understand?
- Was it easy to understand what was happening in the game?
- How did you find the difficulty level of the game?
- Was the speed of the game appropriate?
- Did you like the game?
- How would you rate the game as a form of entertainment?
- How would you rate the game as a test for measuring texture recognition?
- Were you able to recognize the textures of the falling items?
- Was the size of the falling items appropriate?
- Was the speed of the falling items appropriate?
- Please indicate which items had textures that were difficult to recognize.
- Please indicate which items had textures that were easy to recognize.

Items related to usability, visibility, and ease of understanding generally received high ratings. In particular, the visibility of the color scheme, clarity of the interface, and usability of the interface all received high mean ratings of 4.83, suggesting that the visual design and user interface were appropriate. However, several issues related to the UI design were identified. In particular, participants indicated that the collision detection area for the insects was too large, making them difficult to avoid, and that the placement of the *sara-sara* and *zara-zara* buttons made them easy to confuse.

The intuitiveness of game operation (mean = 4.66), clarity of the tutorial (mean = 4.50), and clarity regarding what players were expected to do in the game (mean = 4.66) were also rated highly. The overall comprehensibility of the game system (mean = 4.75) and the ease of understanding what was happening in the game (mean = 4.75) were similarly rated favorably. The free-text responses included comments such as "intuitive and easy to understand" and "the game system is simple and easy to play," suggesting that there were no major problems with the basic game system.

In contrast, ratings related to enjoyment were relatively lower. The mean rating for "Did you like the game?" was 3.83, while the mean rating of the game as a form of entertainment was 3.25, indicating only moderate levels of enjoyment. Free-text responses included comments that "the difficulty level was too low for a game intended primarily for enjoyment," as well as

suggestions for improving the game specifications. Participants also suggested adding more gameplay elements to the falling-object phase and noted that the scoring criteria in the sorting phase were difficult to understand.

At present, the falling-object phase primarily involves collecting falling fruits. Although insects appear as obstacles, there is little opportunity for players to develop strategies or modify their behavior. Furthermore, because the scoring criteria in the sorting phase are not clearly communicated to players, the scoring system may not provide a sufficiently convincing or satisfying gameplay experience. These factors may have contributed to the moderate ratings for enjoyment. Therefore, reducing the monotony of gameplay and clarifying the scoring criteria are important issues for future improvement.

LIMITATIONS AND CONCLUSION

In this study, we developed a game consisting of a falling-object phase and a sorting phase, and evaluated both the game system and the texture items with young healthy participants. The results of the participant experiment showed that the game received high ratings for fundamental system-related aspects, including usability, visibility, and ease of understanding. In contrast, ratings related to the enjoyment of the game remained moderate, indicating the need to improve its gameplay, for example by adjusting the difficulty level and introducing additional game elements. The texture images also require further refinement. In particular, the original texture images and the image-generation method should be reconsidered in order to achieve more consistent representations of texture.

The participants in the evaluation experiment conducted in this study were limited to young healthy adults, and validation with older adults has not yet been sufficiently conducted. Although the size and falling speed of the items were considered appropriate by the young healthy participants, suitable settings may differ for older adults because of age-related declines in visual function and reaction speed.

Further improvements to the game are required. Regarding the user interface, the collision detection areas for insects and fruits should be made more consistent, and the button layout should be revised to reduce erroneous selections between sara-sara and zara-zara. Regarding the game specifications, we plan to enhance gameplay by adding new elements to the falling-object phase. We will also consider revising the scoring system in the sorting phase so that the scoring criteria are easier for users to understand. The texture-item images likewise require further adjustment and refinement.

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