A THREE-LEVEL APPROACH TO UNDERSTAND CULTURAL VARIABILITY AND THE EVOLUTION OF HUMAN ATTENTION

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Attention plays a crucial role in cognition and behavior. To explain the cultural variability of attention, we postulated a general hypothesis of cultural adaptation, which assumes that the attentional mechanism co-evolves with objects in our environment. We employed a three-level approach composed of hypothesis-driven experiments, a large-scale database platform gathering results from various parts of the world (“Kokoro World Map”), and corpus-based analyses. This article reports on an attempt to apply this approach using visual search and the Stroop effect as examples. In visual search task, we began with hypothesis-driven experiments on search asymmetry, and is currently expanding to the construction of large-scale databases using online experiments and an ontology database. In the Stroop task, we constructed ontology and corpus-based analyses to formulate concrete hypotheses about the cultural evolution of cognitive control, which were examined by online and laboratory experiments. From these multi-level approaches, we also try to integrate the findings of cognitive science and those of archaeology and anthropology.

Key words: Kokoro World Map, cultural difference, visual search, Stroop effect, ontology, topic model

INTRODUCTION

In a recent project to build a new research area, “integrative human historical science” (http://out-of-eurasia.jp/en/), researchers from various disciplines including anthropology, archaeology, genetics, history, neuroscience, and psychology are collaborating to understand how humans have constructed a variety of civilizations. A massive challenge is integrating the findings on archaeological records and findings on cognition and behavior to reconstruct human life in the ancient times. This article introduces cross-cultural studies on attention and proposes a three-level approach to address this issue by describing our attempts at cultural differences in visual search and the Stroop effect.

Complementary Roles of Cognitive Science and Historical Science

Cognitive science has primarily focused on understanding the behavior and neural mechanisms of contemporary humans using various experimental techniques. By contrast,
historical science aims to understand how human activities in the past have formed the current status of humans. These two areas have been largely independent of each other, till a recent surge in cultural evolution studies, where historical science and cognitive science play complementary roles in elucidating how human cultures have evolved. Historical sciences, including archaeology and some branches of anthropology (specifically, cultural and social anthropology), provide adequate data to understand how cultures evolve. Moreover, cognitive science hypothesizes about the evolutionary mechanisms, and empirical data on the microscopic processes of social learning.

Studies on cultural evolution postulate that learning is the primary mechanism underlying cultural evolution (Feldman et al., 1996). In Darwinian biological evolution, individual organisms acquire new biological traits by gene mutations, and since environmental capacity is limited, organisms with higher fitness to the environment increase by natural selection. Analogous to mutation and natural selection, cultural evolution can be considered to be driven by the interaction of individual and social learning. Here, we can think of individual learning as enabling innovation, which corresponds to mutations in biological evolution, and social learning as the transmission of cultural traits (Feldman et al., 1996). Studies have proposed mathematical models of cultural evolution (Henrich, 2004; Powell et al., 2009), which are evaluated by both behavioral experiments (Caldwell & Millen, 2009; Derex & Boyd, 2016) and archaeological data (Crema et al., 2016). A typical behavioral paradigm to examine the transmission of cultural traits is the transmission chain paradigm. In a transmission chain experiment (Caldwell & Millen, 2009), a participant made a paper plane trying to lengthen its flight time. Another participant made his/her own plane by looking at the plane made by the previous participant. He/she could either imitate the previous one, or make a new type. This task was a laboratory simulation of cultural transmission in which each participant corresponds to one generation in the cultural evolution. Furthermore, a recent study conducted simulation-based analyses of decorative motifs of Neolithic pottery to evaluate mathematical models of social learning (Crema et al., 2016).

Cultural Adaptation: Another Mechanism Underlying Cultural Evolution

Although social learning is an essential component of cultural evolution, our physical environment also plays an important role in it. Aunger (2002) showed the importance of cultural objects as “crystalized knowledge,” which generates various cultural activities. In addition to learning other people’s behavior, cultural traits can also be transmitted by manipulating cultural objects. This perspective is consistent with the niche construction theory of evolution (Odling-Smee et al., 2003) that emphasizes interactive mechanisms between the physical environment and animals in evolution. However, classical Darwinian theories of biological or cultural evolution tend to consider evolution as adjustment by mutation or innovation to a stable physical environment; the niche construction theory treats evolution as active transformation of environments. Iriki and Taoka (2012) proposed that active transformation of the environment (environmental niche construction) is accompanied by the transformation of internal neural circuits (neural niche construction), which enables transformation of cognition and behavior.
(cognitive niche construction), and called this process, triadic niche construction. It is noteworthy that the environmental niche construction includes both social and physical environments. Thus, the triadic niche construction theory can deal with both social learning and manipulation of cultural objects.

The triadic niche construction is particularly important in understanding the roles of attention in cultural evolution as attention skills seem quite difficult to learn exclusively through social learning. Attention can be considered as control mechanisms of our perception, memory, and thinking. Researchers agree that it consists of two major components: perceptual attention controlling for our cognition of the environment, and cognitive control of our thinking and motor behavior. Cultural psychology studies have reported various cultural differences in perceptual attention, particularly visual attention (Chua et al., 2005). Furthermore, researchers in cognitive archaeology emphasized the role of cognitive control in cultural evolution (Coolidge & Wynn, 2016). Therefore, the role of attention in cultural evolution is an important issue.

Cognitive processes of our attention are usually unobservable from overt behavior, except for a few cases accompanying overt bodily movements. Furthermore, some attentional mechanisms, such as attentional capture and inhibitory control, are automatic and stimulus-driven. These properties make the acquisition of attentional skills, via imitation and direct instruction, difficult. Therefore, cultural traits related to attention are more likely to be acquired through interaction with cultural objects than by social learning. Therefore, it would be appropriate to call this process cultural adaptation.

Three Levels of Investigation to Understand Cultural Evolution of Attention

To understand how our attentional mechanisms adapt to particular cultures, our research group tries to combine three levels of investigation: (1) hypothesis-driven behavioral experiments, (2) a large-scale database across various cultures called “world cognitive map,” and (3) corpus-based analyses to integrate behavioral data and archaeological records. Hypothesis-driven behavioral experiments usually compare two cultures with controlled experiments. The major advantage of experimental studies is that they can address detailed cognitive processes underlying cultural differences; however, because of the use of controlled experimental settings, generalizability to different cultural groups and complex everyday behaviors remains unknown. The world cognitive map plays a complementary role by collecting data from a wide range of cultural groups, and of a wide range of different cognitive tasks through online experiments and construction of a database of psychological research papers. In addition to evaluating the generalizability of the experimental studies, the world cognitive map can provide new hypotheses about the cultural variability to be tested by experimental studies.

Such a reciprocal relationship also exists between the world cognitive map and corpus-based analyses. A major limitation of the world cognitive map is that it includes only behavioral data of presently-existing humans, which are insufficient to understand the process of cultural evolution. The world cognitive map represents the variabilities of cognitive processes among contemporary humans, who are the end-product of cultural evolution. To understand how cultural evolution creates variability in current societies,
we need to integrate the world cognitive map with various data reflecting people living in the past, including cultural objects, and ethnographical resources. To this end, we developed a technique to integrate behavioral data and historical data based on topic models and ontology systems. Simultaneously, corpus-based studies can provide clues about what kind of cognitive processes should be investigated in making the cognitive map.

In this article, we describe our recent attempts toward understanding the cultural evolution of attention. One of the attempts was about the effect of cultural differences in visual search, which addressed issues of visual attention. In this task, we began with hypothesis-driven experiments, expanding to form a large-scale database and corpus-based analysis. The other attempt constructed the world cognitive map of the Stroop effect, which is a standard measure to investigate cognitive control. We began at the level of the world cognitive map by constructing an ontology system of research papers on the Stroop effect, and attempted to proceed in two directions: to formulate specific hypotheses about cultural differences and to integrate cognitive science and historical science using topic model analyses. At the level of the corpus-based analyses, we performed a topic model analysis of psychological research on the Stroop effect; the preliminary results thereof are described in the fourth section.

**Cultural Difference in Visual Search: A Case Study of Cultural Adaptation in Visual Attention**

*Cultural Difference in Visual Search Asymmetry*

Recently, Ueda et al. (2018) reported significant cultural differences in visual search asymmetry between Westerners and East Asians. They used the line length search task originally used by Treisman and Gormican (1988), which had significant search asymmetry. For Westerners, searching for a long line among short lines was significantly more efficient than the other way around. Ueda et al. (2018) conducted a line search task with East Asian (Japanese) and Western (American or Canadian) participants, and revealed that although Western participants replicated the search asymmetry, East Asians failed to show the asymmetry (Fig. 1).

This report of cultural differences in visual search asymmetry is important in some respects. First, unlike many previous studies, the line search task is culturally neutral, which can eliminate accounts based on differences in stimulus familiarity between cultures. Second, the difference in search asymmetry can exclude the account that the cultural difference is due to motivation to the experimental task.

To address the issue of whether cultural differences reflect a general cognitive style, such as holistic vs. analytic processing (Masuda & Nisbett, 2001), Ueda et al. (2018) used other stimulus pairs, namely vertical vs. tilted, and circle vs. circle plus a vertical bar, which are also known to show search asymmetry. These other stimulus sets revealed different patterns of search asymmetry. In particular, with vertical and tilt, East Asians showed a stronger search asymmetry than the Westerners, indicating that cultural
differences in search asymmetry are stimulus-dependent. These results were inconsistent with the popular view that cultural differences in attentional processing reflect general cognitive styles.

A possible concern that exists is whether these findings really reflect cultural differences or other more biological factors, including genetic differences. To address this issue, Cramer et al. (2016) examined line search performance with Chinese and Japanese individuals immigrating to Canada. They compared immigrants who entered Canada at an early age, and those who entered Canada recently, and found that recent immigrants showed a pattern similar to East Asians. However, earlier immigrants behaved increasingly similar to Western participants. It indicates that cultural differences in search asymmetry in line length search reflect visual experiences, not exclusively based on biological factors.

Overall, a series of studies on cultural differences in visual search asymmetry have demonstrated substantial cultural differences in basic visual search performance, which is not confounded by motivation, stimulus familiarity, and genetic factors.

Cultural Adaptation: A Hypothetical Mechanism Underlying Cultural Evolution of Vision Cognition

The findings of Ueda et al. (2018) and the basic mechanisms of visual search provide some constraints on the possible mechanisms. This is beneficial in understanding the way cultural differences in visual search asymmetry emerge through cultural evolution. The cultural differences in visual attention exemplified by visual search are inconsistent with the standard mechanism of cultural evolution, namely social learning (Feldman et al., 1996). In the literature on cultural evolution, social learning, including imitation, has been considered as the principal mechanism driving cultural evolution.
Both field and experimental studies investigated overt behavior, such as tool use, tool making, and body movement, which are observable and, therefore, can be learnt by imitation. By contrast, visual search is mainly composed of covert behavior, in which the performance of the searcher is evaluated by response time or eye movement in an experimental setting. These measures are difficult to investigate in real life settings, and it is unlikely that people learn searching by observing other people’s eye movements or search times.

An alternative mechanism underlying the cultural evolution of visual attention is cultural adaptation. Cultural evolution transforms our external environment by creating various artifacts such as tools, buildings, clothes, and ornaments; consequently, visual environments differ substantially across different cultures. Our visual cognition has been adapted to our own environment for efficient behavior. Therefore, our visual cognition may show subtle, but substantial differences across different cultures, as demonstrated by Ueda et al. (2018). We refer to this as cultural adaptation hypothesis.

To obtain evidence for the cultural adaptation hypothesis, in the case of visual search asymmetry, we need a concrete hypothesis on visual information to be culturally adapted. Thereafter, we need empirical evidence from behavioral experiments and computational modeling. Behavioral experiments examine whether the hypothesized factors indeed lead to differences across cultural groups. Likewise, computational modeling is important, because real cultural adaptation is a long-term process spanning years, which is beyond the scope of empirical studies.

We hypothesized that cultural differences in visual search asymmetry are mediated by (1) orthographical systems (letters) and/or (2) statistical properties of visual scenes.

**Behavioral Experiments to Examine the Cultural Adaptation Hypothesis**

Eastern and Western cultures, which Ueda et al. (2018) contrasted, differ in various aspects including social system, language, orthography, and visual environment. To examine whether orthographical systems and/or visual scenes play crucial roles in cultural differences in visual search, more focused comparisons based on specific hypotheses need to be conducted. For this purpose, we are underway to examine the effect of orthographical systems by comparing line length search performance in Japanese, Taiwanese, and Korean participants. In cultural psychology, these groups are treated similarly, and many previous studies have reported similar results. However, from the perspective of orthography, these three groups use quite different systems. In particular, the Korean alphabet (Hangle) is similar to the English alphabet, both of which denote pronunciation, whereas Chinese and Kanji in Japanese characters denote both pronunciation and meaning. Thus, although the socio-historical environment is quite similar across these cultural groups, the cultural adaptation hypothesis predicts that search performance of the Korean will be similar to Westerners. The preliminary experiment comparing the default performance of Japanese and Taiwanese participants shows supporting data; thus, we now collect more convincing evidence. Taiwanese data consistently show a lack of search asymmetry with line length search, akin to Japanese participants (Ueda et al., 2019).
Regarding the statistical properties of scenes, a report mentions that Japanese and American scenes have different statistical properties (Miyamoto et al., 2006). Ueda and Komiya (2012) showed that exposure to visual scenes in one culture produces adaptation effects on visual processing. These studies are initial investigations of the effects of the statistical properties of scenes on visual cognition, but which properties are critical remains unknown. Thus, further systematic image analyses using a large-scale data set are necessary.

**Computational Modeling to Examine the Cultural Adaptation Hypothesis**

Cultural adaptation itself requires long-term visual experience; thus, it is quite difficult to obtain direct behavioral evidence from behavior experiments. To avoid this limitation, we conducted computational modeling to support the cultural adaptation hypothesis.

Saiki (2020) examined the role of orthographical systems in visual search asymmetry with line length by employing a saliency map model called attention based on information maximization (AIM) model (Bruce & Tsotsos, 2009). The AIM model can simulate search asymmetry, which was impossible with the original saliency map model by Itti and Koch (2000). A critical feature of the AIM model is that the features to calculate the saliency map are defined by a set of basis functions derived from independent component analysis (ICA) of a large set of natural images. It can be considered as implementation of feature extraction by long-term visual experiences. Thus, by comparing model performance by changing different basis functions using different image sets, we can investigate the effects of long-term visual experiences.

Another important feature of the AIM model is the use of a pooling window as a simulation of the attentional window. The pooling window is a Gaussian filter to smoothen the information value computed for each pixel. However, this can be considered as the size of the attentional window to aggregate information. Thus, by manipulating the window size, we can investigate the effects of attentional window size on salience map formation.

Saiki (2020) computed the saliency maps of the line search displays in Ueda et al. (2018) using the AIM model by manipulating the pooling window size systematically. Additionally, he conducted simulations with four different sets of basis functions derived from natural images (the original model), alphabets, Kanji (Chinese) characters, and Hiragana. Search efficiency was evaluated by the frequencies of the most salient location being at the target item. The AIM model successfully simulated the search asymmetry of line length search at the default setting, which extends the findings of Bruce and Tsotsos (2009). Notably, by decreasing the attentional window size, search asymmetry disappeared. Finally, changes in search asymmetry across different window sizes showed substantially different patterns across different basis functions, suggesting that long-term visual experiences modulate search asymmetry.

Collectively, the AIM model can account for changes in search asymmetry by changing the attentional window size; the smaller window size eliminates search asymmetry. This is indeed opposite to the standard cultural psychology conception that
persons of East Asia origin are more holistic in visual processing. According to the AIM model, East Asians who show no search asymmetry, have a smaller attentional window than Westerners in visual search. This difference can be interpreted by different orthographical systems between the two cultures. In some East Asian written languages (e.g., Kanji characters), a single letter denotes a semantic unit and has a complex shape; thus, narrowly focused attention is more adaptive. Contrastingly, in Western cultures using alphabets, a set of letters denotes a word, and each letter has a simple shape; thus, a broader attention window is more adaptive. Importantly, this is a hypothesis testable by behavior experiments, which needs to be done in a future study.

To examine the effects of the statistical properties of scenes using computational modeling, an exploratory analysis using a large number of scene images from different cultures is necessary, which is currently under investigation. A big data approach can help reveal critical properties that produce cultural differences in visual cognition, which enables us to examine whether they are really critical in behavior experiments. Moreover, this approach extends our scope through a comparison of two cultures to a large-scale comparison covering the whole world, which leads to the “Kokoro World Map” that is based on the concept of a world cognitive map.

**Making “Kokoro World Map”**

*The Importance and Necessity of the World Cognitive Map for Understanding Human Cognition*

Humans have achieved biological prosperity by adapting their information processing to their ecological and behavioral environments. Different environments lead to different fluency of information processing because the frequency of exposure to certain information is different, which makes the degree of repetition of the same process, different (for example, face, Malpass & Kravitz, 1969). A cultural difference in the visual search task discussed in the previous section is an example of the same. Furthermore, humans have constructed their own ecological and behavioral environments by creating norms and establishing institutions, habits, and common knowledge based on the ideas they have developed. These facts have decisive implications for psychological theory; various psychological processes, including perception, cognition, and emotion, are shaped by human’s efforts to adapt to their ecological and behavioral environments. Cultural comparison is one of the challenges to reveal our psychological processes from this perspective. However, many studies dealing with such cultural differences have been limited to comparisons between a few areas (often two) between Western Europe, North America, China, and Japan. To understand the essence of the human mind, it is also necessary to compare it with other regions, such as the Middle East, Africa, Latin America, and Oceania.

In this study, we refer to the representation of such cognitive variation using a large dataset (including thousands of participants from many countries) as the world cognitive map. Several studies have already taken this approach; Thomson et al. (2018) described
social behaviors by relational mobility, the fluidity of relationships with others, with over 16,000 participants in 39 countries. Their finding suggests that higher relational mobility predicts more proactive interpersonal behaviors. Awad et al. (2020) also investigated the tendency of response to sacrificial dilemmas (a type of moral dilemmas) in 70,000 participants in 42 countries, and showed that acceptance of sacrificing one life to save several varied greatly country-wise. Furthermore, it is associated with relational mobility. Sorokowska et al. (2017) examined preferred interpersonal distance among more than 8,000 participants in 42 countries. They found that preferred interpersonal distance was influenced not only by individual characteristics (age and gender in their study), but also by the climate of the region of data collection. This is an interesting study as it provides evidence that variation in human cognition is determined not only by social learning, but also by the environment in which people live.

However, these studies were based on questionnaire surveys, and few studies on basic perceptual phenomena observed in laboratory (or well-controlled environments) have been conducted across various regions of the world. Perhaps a more serious concern is that they have drawn “conclusions” from several limited issues and do not provide a full picture of human minds. In order to understand how humans perceive their minds and the world, we must overcome these problems.

A Concept of “Kokoro World Map”

To understand how humans form cognition of the world and predict their behaviors in a certain situation (or task), it is necessary to consider the relationship between the performance of various tasks (not only “higher-order thinking” but also “basic perception”). Furthermore, we have to associate them with the environment where people live from multiple perspectives (e.g., streetscape, language, social structure, history, and religion) to clarify what makes our minds and its diversity. The method we proposed in this section is to conduct experiments including behavioral responses with systematizing methods (the same instructions, stimuli, and data analysis methods) and to build a large database gathering the results conducted in various parts of the world.

We referred to this platform as “Kokoro World Map.” Fig. 2 shows a schematic illustration. Cross-cultural comparison in visual search asymmetry is the initial step and a part of it. However, if one researcher or one research group conducts any kinds of psychological laboratory experiments throughout the world, it will soon exhaust its human and time resources. Likewise, even if a consortium is established with dozens or hundreds of researchers (and this is an attempt to be tested in practice), it is extremely difficult to conduct all kinds of experiments across the world. To resolve this difficulty, we proposed this schema, including two types of investigations: crowdsourcing, and collecting the results of various experiments that had ever been conducted. This will enable us to save a lot of time and effort, and have an idea what we should investigate with elaborate hypothesis-driven behavioral experiments. The platform created in this way will serve as a foundation for psychological research by complementing past knowledge in psychological experiments with systematic and latest acquisition of novel data across the world.
Fig. 2. A Schematic Illustration of “Kokoro World Map”

Note. This platform consists of a database of past research, and novel experiments conducted based on a common protocol. By mapping out the similarity in performance of each task, we can examine the performance variability across countries/regions within a task, and then, examine the consistency across tasks. This enables us to depict characteristics of a region and to understand how to form our mind.

Online experiments to collect behavioral data worldwide. The first approach, crowdsourcing is the requirement of work to an unspecified large number of people (mainly via the Internet) for free or low compensation. Although questionnaires have been mainstream of research using this, an increasing number of studies have used it to examine cognitive processes (Buhrmester et al., 2011; Majima, 2019; Stewart et al., 2017). Moreover, to use this technology in cognitive tasks, new methods have been proposed that allow us to perform tasks such as adjusting the size of the visual angle over the Internet, which had previously been performed only in the laboratory (Li et al., 2020).

Online experiments are generally less precise than laboratory experiments, and there are limitations to what can be done. For example, the visual search task in Ueda et al. (2018) takes one hour to complete data collection from one participant, and it was conducted in a dimly-lit room. It is difficult to conduct the same experiment online because we are not able to check and control their circumstances during the experiment. Therefore, tasks must be adjusted to meet these limitations. In a visual search task using the reaction time as a dependent variable, several dozen trials will be required to achieve stability; thus, it is necessary to develop a way to shorten the experiment time. For
example, the presentation time of the search display is fixed, and the percentage of correct responses regarding the presence or absence of the target is recorded. The data obtained in this way may not be as accurate as the data from laboratory experiments, but it is possible to get an idea of whether the trend is the same regardless of regions, or whether there are variations. In addition, data on other issues that might be related to search performance (e.g., fluency of text processing) are obtained at the same time, which would shed light on what determines our behavior.

This approach has been advanced for visual search, but similar strategies could be used for other cognitive tasks.

Pool past findings using an ontology. For the second approach, past results should be collected to allow flexible comparisons among them. One solution for this is to use ontology. Ontology is a method that has been developed in the field of information science to describe the relationships between concepts within a common domain. By including the regions where the psychological experiment was conducted, demographic data of participants (age, race, place of residence, language, psychological disorders, etc.), methods, and task performance in an ontology, we will be able to extract and examine the differences in psychological processes from various perspectives. Although some studies have modeled relationships between concepts of cognitive processes (e.g., cognitive atlas by Poldrack et al., 2011), there is no database that includes the results of the effect size of the experiments. This is one of the barriers to systematic comparisons of past findings to understand whether similar results are obtained in all regions or whether there are variations in our information processing such as perception and cognition.

Here, we treated the Stroop task as an example for an ontology because this task has been performed more frequently across various parts of the world compared with a visual search task; furthermore, cultural differences are also reported. In the Stroop task, participants are required to read out or respond to the meaning of a presented word ignoring irrelevant information (e.g., read out a color-word ignoring a color of it; Stroop, 1935). They must focus on task-relevant information while suppressing task-irrelevant information, and it has been suggested that this behavior is associated with a psychological process called executive function and brain activity in the frontoparietal network (e.g., Dixon et al., 2018). From a basic experimental psychology perspective, the Stroop task is related to both the inhibitory process activated in the go/no-go task and the task switching process (see Friedman et al., 2008). The Stroop task has been used not only in experimental psychology but also in clinical and developmental psychology. Additionally, it has been reported that similar results are obtained in most of studies (i.e., response is quicker and more accurate when task-irrelevant information is congruent with task-relevant information than when it is incongruent). For cultural differences, specifically in emotional Stroop tasks, Japanese participants were more influenced by task-irrelevant emotional intonations even while reacting to the emotion of the presented words and faces compared with Dutch and US participants (Ishii et al., 2003; Tanaka et al., 2010). However, cultural differences have not been reported in the classical color-word Stroop, and it is not clear whether people belonging to one culture (e.g., Japan) are generally
more vulnerable to task-irrelevant features, or whether this difference is observed only in
certain tasks (e.g., emotional Stroop). Therefore, gathering the results of various Stroop
tasks conducted across the world, we can get a rough idea of whether the trend is the
same regardless of regions, or variations. In addition, since the Stroop task is strongly
associated with executive function, it can also provide insightful clues in understanding
not only cultural differences but also a wide range of individual differences including
personality (e.g., Miyake & Friedman, 2012).

Our attempt to build the basic structure of an ontology based on the Stroop task is
shown in Fig. 3. The structure of this ontology was constructed by the authors, based on
a review of previous studies, using the Stroop task. Ontology represents the relationships
between concepts with a three-word set; that is, “what concept (i.e., subject),” “has a
property (i.e., verb),” “for the concept (i.e., object).” For example, Fig. 3 represents
“research paper investigates the Stroop effect” and “the Stroop effect is measured by
color-word Stroop task.” Furthermore, “research paper consists of the experiments,”
“each experiment collects participants,” “each experiment results effect size in the Stroop effect and reaction time/accuracy,” “the participants live in country/region and have a job and physical/mental illness.” By tracing these relationships, we can connect concepts to concepts; for example, the effect size that Japanese people show in the color-word Stroop task. Likewise, using this structure, we can flexibly summarize the effect from the studies that were conducted in a certain country/region or that recruited people with a certain psychological disorder.

The hierarchy below “experiment” is basically the same regardless of tasks; therefore, the ontology structure can adopt any study (i.e., other visual cognitive tasks including visual search) and not only the Stroop task. Gathering and mapping the results of the same experiments from multiple studies, we roughly examine the variance of cognitive processes between regions with saving efforts for the laboratory experiment.

Bridge Between Laboratory Experiments and Other Disciplines

The “Kokoro World Map” is a platform that aggregates worldwide experiments using crowdsourcing methods and ontology-based databases. These two approaches are complementary to each other. This is because summarizing databases can predict consistency and differences between cultures and tell us what protocols will work best for replication experiments and new tests. Simultaneously, adding the results of worldwide experiments under the common protocol to the database, it will be expanded and will be able to more accurately draw cultural consistency and differences. We can thus derive hypotheses based on the variability of the information processing represented in this map, and move on to laboratory experiments when we need to obtain precise data based on the hypotheses introduced in the previous section.

CORPUS-BASED ANALYSES TO INTEGRATE BEHAVIORAL DATA AND ARCHAEOLOGICAL RECORDS

Building a Research Database Related to the Creation of Cultural and Regional Products

As described in the Introduction, there is a persistent need for psychology and cognitive science to contribute to other academic disciplines. Recently, the focus has shifted on cognitive archaeology, which is the study of cognitive evolution by applying the theories of cognitive science to archaeological products of the prehistoric past (Coolidge & Wynn, 2016; see also Gönlü et al., 2018; Putt et al., 2019). Putt et al. (2019) argued about the importance of enhanced working memory abilities, which may be related to executive control, such as sequential reasoning, inhibition, and planning, in the development of stone age tools. Executive function is one of the most important themes of cognitive science, which includes visual search and visual working memory (e.g., Luck & Vogel, 1997). Due to its importance, numerous papers related to executive control have already been published. To understand the trends of the specific themes of cognitive science, it is effective to collect a significant amount of data from previous cognitive science studies and build a large-scale database. Rahnev et al. (2020) created a
confidence database, which is a collection of studies related to subjective confidence judgments of participants’ consciousness. In 2020, this database contained 145 datasets with more than 8,700 participants and 4 million trials. Building a research database of executive function related to cognitive evolution will contribute to the elucidation of the interaction between human cognition and the creation of cultural and regional products, including human environments (e.g., paintings, tools, and myths from ancient times to the present).

A Meta-Analysis of a Large-Scale Dataset

We argue the effectiveness of building a large-scale database of cognitive science in this study. However, it is time-consuming and labor-intensive to collect papers and grasp every detail in specific themes of cognitive science. Consequently, there have been reviews of previous studies and meta-analyses to summarize the findings. Robbins and Chapman (2019) performed a meta-analysis of papers limited to visual search for novice and experienced drivers. Rey-Mermet and Gade (2018) conducted a meta-analysis of 176 studies that measured inhibitory processes in cognitive performance in terms of aging research. Song et al. (2017) conducted a meta-analysis of papers limited to neuroimaging studies and the emotional Stroop task. The suggestions from the meta-analysis with hundreds of papers, although not all, should be dependent on the themes that the researchers selected. The results of the above meta-analysis represent a limited trend in the themes of cognitive science (Wang et al., 2016). Therefore, we aim to overview the trends of specific themes of cognitive science without possibly making it time-consuming and arduous; it will be effective to conduct a meta-analysis on datasets from a large-scale database using an unsupervised machine learning technique. Rubin et al. (2017) conducted topic modeling, a text mining technique with machine learning, to decode brain activities with large-scale datasets of the functional brain atlas of human cognition and its corresponding abstracts of 11,406 published fMRI studies. As evident in previous studies of cognitive neuroscience, their results suggested a correspondence between each topic such as reward, emotion, memory, and face perception, as well as the brain regions engaged in these topics (the ventral striatum, amygdala, hippocampus, and fusiform face area, respectively). Further, they illustrated the relationship between the topics related to visuospatial processing and working memory and the brain areas of the intraparietal sulcus (e.g., Todd & Marois, 2004). This type of meta-analysis with large-scale text data and its corresponding data connected with each document (e.g., behavioral responses and brain regions), allows us to provide a detailed portrait of specific themes in cognitive science.

Text Mining Approach on a Large-Scale Database

According to the text mining approach, in this study, we introduced several studies using topic modeling with latent Dirichlet allocation (LDA; Blei et al., 2003) for the abstracts of scientific papers. Both a hypothesis-driven experiment and an online experiment, as described in the previous sections, can only capture the current trends of human visual cognition. Additionally, it is common that reviews or meta-analyses focus
on specific themes only with some dozens of articles, whereas a huge number of articles in cognitive science, including physiological science and neuroscience, have already been published in various types of scientific journals. In contrast, one of the important advantages of the text mining approach using unsupervised machine learning on the abstracts of scientific papers is that we can include studies from past to present, which will lead to an overview of trends of human visual attention. We introduced an alternative approach for surveying previous studies of cognitive science, text mining, which is a process of extracting statistical patterns and trends from an enormous number of text datasets.

Topic modeling is the probabilistic modeling of text mining to identify topics that have meaningful structures within collections of documents. It is used to identify the latent topics related to a document and to overview the topics in the collections of all documents. Recently, text mining techniques with topic modeling have been applied to not only open-ended survey responses in the American National Election Study (Roberts et al., 2014) and to review comments for commercial products on online shopping websites (He et al., 2020), but also to the abstracts of scientific articles and annual meetings (Griffiths & Steyvers, 2004; Myers, 2020; Wang et al., 2016). Griffiths and Steyvers (2004) conducted topic modeling for the abstracts of articles published in Proceedings of the National Academy of Sciences from 1991 to 2001 and demonstrated that the topics extracted on topic modeling are consistent with the article classifications that the authors selected. Wang et al. (2016) used topic modeling for the abstracts of articles related to adolescents and depression, and suggested that text mining can be used as a tool to recapture the facts that have already been known and to uncover hot and cold topics.

According to these previous studies of topic modeling, we conducted LDA topic modeling (Blei et al., 2003) for the abstracts of manuscripts that we searched on the PubMed database with the keywords “visual search” or “Stroop.” Fig. 4 illustrates the top 10 probable words of topics within the documents of “visual search” and “Stroop.” We observed not only the topics related to the basic words about the experiments of
visual search and Stroop test (e.g., attention, capture, distractor, conflict, trial, and incongruent), but also those related to words about clinical, developmental, and neuroscience studies (e.g., depress, children, and frontal). In addition, we conducted structural topic modeling (STM; Roberts et al., 2014) for these abstracts related to visual search and Stroop test with geographic regions where the first author’s affiliation exists as covariates. Roberts et al. (2014) introduced STM, in which researchers can examine whether the prevalence of each topic is influenced by covariates attached to each document (e.g., the author’s gender and age, and political affiliation attached to open-ended survey responses). As a result, the probability of occurrence of the topic consisting of the basic words of the Stroop test was found to be higher in North-Central America than in Europe and Asia, whereas the occurrence of topics related to clinical research was higher in Europe than in North-Central America, irrespective of visual search or Stroop test. At this point, the findings on topic modeling are not connected with psychological aspects of human participants. In future research, we should conduct additional topic modeling to examine whether the probability of occurrence of topics in specific themes of attention will change across participants’ information, publication periods, and effect size, using the ontology database of cognitive science (Poldrack et al., 2011) described in the third section.

This additional analysis will lead to the development of the world cognitive map and clarify the cultural variability of human attention. Alternatively, we can connect an ontology database of cognitive science with that of archaeology, including cultural products such as the paintings, tools, and myths from ancient times to the present, and examine what latent topic exists within the documents and changes across the regions and periods. Of course, archaeologists and cognitive scientists need to collaborate toward improving the above database. We are confident that these studies will lead to a comparison of cognitive science with cultural and regional products, including human environments.

**General Discussion**

In this paper, we introduce a three-level approach of cognitive science research on the cultural evolution of attention: hypothesis-driven behavioral experiments, a large-scale database across various cultures called “world cognitive map,” and corpus-based analyses to integrate behavioral data and archaeological records. Hypothesis-driven experiments can allow us to control various factors, such as visual stimuli, responses, and experimental settings. Unsurprisingly, it is important to control and manipulate the factors that have the potential to influence the results of experiments. By conducting a hypothesis-driven experiment, we can determine a cause-and-effect sequence of events, leading to a better understanding of the mechanisms. However, it is difficult to collect behavioral responses from a large number of participants in a short period and from different geographic regions.

Recently, apart from well-controlled procedures, some researchers have conducted
large-scale online surveys and experiments by asking for help from crowdsourcing such as Amazon Mechanical Turk. According to online surveys and experiments, we can capture the trends of human attention in broad areas. In addition, this type of online experiment may play an important role in the replications of individual and well-controlled experiments (e.g., Sherman & Turk-Browne, 2020).

Many psychologists understand that they explore human behavior at present in their surveys and experiments. Although they discuss their results in comparison to the findings of previous studies, it is difficult to clarify whether behavioral responses in a cognitive task change through age based on the present surveys and experiments. Therefore, to overview the trends of human behavior, we discussed in the third and fourth sections that it is effective to build a large-scale database, or ontology (e.g., Poldrack et al., 2011), of human attention. In addition, we introduced a text mining approach with LDA topic modeling (Blei et al., 2003) for the abstracts of papers that have been published to date. Through an interactive research combining a large-scale database with a text mining approach, we can overview the trends of human attention beyond time and place, which in turn will lead to a new research plan for individual and online experiments. Note that the research levels proposed here can be applied not only to human attention, such as visual search and Stroop task, but also on other topics such as social, developmental, and clinical psychology. In addition, although topic modeling has been used for text data in many previous studies, it can be applied to image and music data. Therefore, research on topic modeling has the potential to clarify the interaction between human attention and creative activity, including the paintings, tools, music, and myths from ancient times to the present. This interdisciplinary research in archaeology and cognitive science will provide suggestive evidence for how the evolution of big brains and cognition may change our living environments, which in turn may fuel the evolution of big brains and cognition (i.e., triadic niche construction of interactions among environment, cognition, and brain; Iriki & Taoka, 2012).

We considered both visual search and the Stroop test as an example to examine cultural differences in human attention. Considering that it is difficult to learn the internal attentional control and cognitive control required in each task from another person, the observed differences in these tasks have the potential to reflect the triadic niche construction (Iriki & Taoka, 2012). Additionally, a three-level approach of cognitive science composed of hypothesis-driven experiments, world cognitive map, and corpus-based analysis will realize the contribution of human attention to integrated human history.

**AUTHOR’S CONTRIBUTION**

Y.U., S.O., and J.S. drafted the manuscript and approved the final version of the manuscript for submission. Y.U. and S.O. equally contributed, and J.S. corresponds.
CONFLICT OF INTEREST

There are no conflicts of interest to be declared.

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