RNMH2012

The First International Conference

Replacement of Neanderthals by Modern Humans: Testing Evolutionary Models of Learning

November 18-24, 2012, Tokyo

Edited by
Takeru Akazawa &
Yoshihiro Nishiaki

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RNMH Project Series

Contents

Preface

Modern humans, whose origins lie in the African continent of around 200,000 years ago, began to migrate to the Middle East and Europe by 50,000 years ago, replacing the Neanderthals who had originally inhabited those regions. What actually happened when modern humans encountered Neanderthals? There may have been some interbreeding, but ultimately modern humans were to replace Neanderthals. The background to the extinction of the Neanderthals, anatomically distinct from modern humans while still being extremely close to them, and the contrasting success of modern humans is a research topic of unmatched interest in the debate surrounding the emergence and spread of modern humans.

There are already a number of theories for the Replacement of Neanderthals by Modern Humans (RNMH), including the neural theory and the population theory. What many of the existing theories have in common is the suggestion that the cultural and technological adaptive capacities of Neanderthals and modern humans to their environments were different. The adaptability of humans is heavily dependent upon culture, and culture is fostered through learning. From this, it is easy to imagine how the nature of learning could have been a major factor for the divergence in the adaptive capacities of the two populations. Was the difference between the relative learning capacities of Neanderthals and modern humans inherent? And was it a decisive factor in causing the replacement of Neanderthals by modern humans? This supposition has been deemed the "learning hypothesis," and

the RNMH Project was launched in 2010 in order to examine this working hypothesis from multiple approaches.

The Project brings together around 80 researchers from multiple fields, engaged in collaborative research. Prehistoric archaeology examines what physical evidence there is to support the differences in the learning behaviors of the two populations, while cultural anthropology looks at the nature of learning in modern hunter-gatherer cultures and creates interpretive models for archeological records. Theoretical biology provides theoretical evidence supporting the learning hypothesis, while paleoclimatology and environmental science provide supporting evidence for the differences in the respective capabilities of both populations to adapt to environments. Fossil engineering is used to understand the morphology of the brains of fossil hominids, while neuroscience seeks to map the parts of the brain related to learning.

The Project is initially being conducted on a five-year basis. This Conference has been planned to mark the mid-way point of the Project, and to set out the direction and goals of the Project going forward. This Conference has two specific objectives: First, the presentation, by a number of Japanese researchers and joint researchers from overseas, of interim reports detailing progress in the RNMH Project. Second, the measurement of progress in verifying and developing the learning hypothesis by having integrated the successes achieved thus far by other researchers working on similar research projects in related fields. Keynote presentations will be given by researchers working in fields that have made significant contributions to this field so far— prehistoric archaeology, theoretical biology, cognitive archaeology, fossil engineering—followed by five sessions on core themes: (1) The process of RNMH: global and comprehensive explanatory models, (2) Learning behaviors in prehistoric and modern humans, (3) Human-specific learning strategies and cultural evolution, (4) Towards digital reconstruction of fossil crania and their brain morphology, and (5) Neuroimaging approach to the learning hypothesis. The Conference will also feature a large number of related poster presentations.

Over six days, the Conference will be a platform for lively debate that will hopefully lead to progress in our understanding of the true nature of the Neanderthals and that of us, modern humans. Of course, the verification of the learning hypothesis is our goal, but a greater achievement would be the simultaneous generation of a new problem-solving perspective. The Conference has been generously supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan. Thanks are also extended to the members of the Steering Committee for Scientific Research on Innovative Areas, as well as staff at the National Institute of Informatics, who organized the venue.

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RNMH2012
The First International Conference

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Shiro Ishii
Tasuku Kimura
Ofer Bar-Yosef
Ralph L. Holloway

Conference Program

Oral Presentations

Each presentation consists of a 40-minute talk, followed by a 15-minute discussion.

The Opening Keynote Lectures

12:00–13:00	Registration
13:00–13:15	Takeru Akazawa, Kochi University of Technology, Japan Opening Remarks

Chair: Yoshihiro Nishiaki

13:15–14:10	Ofer Bar-Yosef, Harvard University, USA	024
	Neanderthals and Modern Humans – A Global View: Isolation, Expansion, Competition, and Demise	
14:10–15:05	Nicole Creanza, Laurel Forgarty, and Marcus W. Feldman*, Stanford University, USA	027
	Exploring Cultural Niche Construction from the Paleolithic to Modern Hunter-Gatherers	
15:05–15:20	Coffee Break	
15:20–16:15	Steven J. Mithen, University of Reading, UK	028
	Neanderthals and Modern Humans – A Cognitive View: Intelligence, Symbolism and Language	
16:15–17:10	Christoph P. E. Zollikofer* and Marcia Ponce de León, University of Zurich, Switzerland	030
	The Reconstitution of the Neanderthal Brain	
17:30–	**Welcome Party**	

Oral Presentations

The Process of RNMH: Global and Comprehensive Explanatory Models

9:00–10:00	Registration

Chair: Seiji Kadowaki

10:00–10:55	João Zilhão, University of Barcelona, Spain ⸻ *034*
	The Replacement of Neanderthals by Modern Humans in Europe
10:55–11:50	Ran Barkai* and Avi Gopher, Tel Aviv University, Israel ⸻ *035*
	Cultural and Biological Transformations in the Middle Pleistocene Levant: A View from Qesem Cave, Israel
11:50–13:00	Lunch Break
13:00–13:40	Poster Session: Group A01/A02

Chair: Akira Ono

13:45–14:40	Seiji Kadowaki* and Katsuhiro Sano, Nagoya University, Japan ⸻ *038*
	From the Beginning: Tracing the Patterns of Cultural Changes of Early *Homo sapiens* in Africa, West Asia, and Europe
14:40–15:35	Hirofumi Kato* and Masaki Naganuma, Hokkaido University, Japan ⸻ *040*
	Thinking the Beginning of Early Upper Palaeolithic in Siberia and Central Asia
15:35–16:00	Coffee Break

Chair: Naoko Matsumoto

16:00–16:55	Ayako Abe-Ouchi*, Yusuke Yokoyama, Hodaka Kawahata, Takashi Oguchi, and Minoru Yoneda, The University of Tokyo, Japan ⸻ *042*
	Investigation of Past Climate and Vegetation for Understanding the Replacement of Neanderthals by Modern Humans
16:55–17:50	Steven L. Kuhn, University of Arizona, USA ⸻ *044*
	Cultural Transmission, Institutional Continuity and the Persistence of the Mousterian

Closing Remarks

Oral Presentations

Learning Behaviors in Prehistoric and Modern Humans

9:00–10:00	Registration

Chair: Hideaki Terashima

10:00–10:55	Hideaki Terashima, Kobe Gakuin University, Japan ⸻ *045*
	Evolutionary Development of Learning and Teaching Strategies in Human Societies
10:55–11:50	Jun Takakura, Hokkaido University, Japan ⸻ *048*
	New Insights into the Skill Learning Processes in the Lithic Production: An Analysis of the Refitted Material from the Kyushirataki 15 Site in Hokkaido, Northern Japan
11:50–13:00	Lunch Break
13:00–13:40	Poster Session: Group A01/A02

Chair: Steven L. Kuhn

13:45–14:40	Yoshihiro Nishiaki, The University of Tokyo, Japan ⸻ *050*
	"Gift" as a Means of Cultural Transmission: An Archaeological Implication of Bow and Arrow Technology in Papua New Guinea
14:40–15:35	Shiro Horiuchi, and Sachiko Kubota ⸻ *053*
	The Effects of Cross-Boundary Rituals on Cultural Innovation
15:35–16:00	Coffee Break
16:00–16:55	Barry S. Hewlett, Washington State University, USA ⸻ *055*
	Teaching, Trust, and Early Rapid Social Learning in Hunter-Gatherers
Closing Remarks	

Wednesday, November 21, 2012
Holiday/Excursion

Oral Presentations

Human-Specific Learning Strategies and Cultural Evolution

9:00–10:00	Registration

Chair: Kenichi Aoki

10:00–10:55	Kenichi Aoki, The University of Tokyo, Japan *056*
	Determinants of Cultural Evolutionary Rates
10:55–11:50	Joe Yuichiro Wakano, Meiji University, Japan *058*
	Scheduling of Individual and Social Learning as Optimal Life History Strategy
11:50–13:00	Lunch Break
13:00–13:40	Poster Session: Group B01/B02/C01/C02

Chair: Laurent Lehmann

13:45–14:40	Laurent Lehmann, University of Lausanne, Switzerland *060*
	The Handaxe and the Microscope: Experience-Based and Fictitious Learning in a Geometric Model of Adaptation
14:40–15:35	Nobuyuki Takahashi*, Ayaka Hatano, Misato Inaba, Ryoichi Onoda, and Dora Simunovic, Hokkaido University, Japan *061*
	Social Learning, Trial-and-Error, and Creativity
15:35–16:00	Coffee Break
16:00–16:55	Alex Mesoudi, Durham University, UK *063*
	Experimental Studies of Modern Human Social and Individual Learning in an Archaeological Context: People Behave Adaptively, but within Limits
Closing Remarks	

Oral Presentations

Towards Digital Reconstruction of Fossil Crania and their Brain Morphology

9:00–10:00	Registration

Chair: Naomichi Ogihara

10:00–10:55	Naomichi Ogihara*, Takeo Kikuchi, Yusuke Morita, Hideki Amano, Osamu Kondo, Masato Nakatsukasa, Hiromasa Suzuki, Takashi Michikawa, Hajime Ishida, and Takeru Akazawa, Keio University, Japan .... *066* Digital Reconstruction of the Neanderthal Amud 1 Cranium
10:55–11:50	Emiliano Bruner, Centro Nacional de Investigación sobre la Evolución Humana, Spain .... *068* Functional Craniology, Human Evolution, and Anatomical Constraints in the Neanderthal Braincase
11:50–13:00	Lunch Break
13:00–13:40	Poster Session: Group B01/B02/C01/C02

Chair: Marcia Ponce de Leon

13:45–14:40	Osamu Kondo*, Daisuke Kubo, and Naomichi Ogihara, The University of Tokyo, Japan .... *070* Virtual Endocast of Qafzeh 9, A Representative of Early Modern Humans
14:40–15:35	Yasushi Kobayashi*, Toshiyasu Matsui, Yoshinori Haizuka, Naomichi Ogihara, Naoki Hirai, and George Matsumura, National Defense Medical College, Japan .... *072* Cerebral Sulci and Gyri Observed on Macaque Endocasts
15:35–16:00	Coffee Break
16:00–16:55	Takanori Kochiyama*, Hiroki C. Tanabe, and Naomichi Ogihara, Kyoto University, Japan .... *074* Reconstruction of the Brain from Skull Fossil Using Computational Anatomy
Closing Remarks	

Oral Presentations

Neuroimaging Approach to the Learning Hypothesis: Learning, Creativity, and Social Cognition

Chair: Hiroki C. Tanabe

9:00–9:55	Hiroki C. Tanabe, Nagoya University, Japan	*076*
	Innovative Society and Social Brains	

9:55–10:50	Dietrich Stout, Emory University, USA	*078*
	Social Neuroscience of Stone Tool-Making Skill Acquisition	

10:50–11:10	Coffee Break

Chair: Dietrich Stout

11:10–12:00	Hiroaki Kawamichi*, Kazufumi Yoshihara, Ryo Kitada, Masahiro Matsunaga, Akihiro Sasaki, Yumiko Yoshida, Haruka Takahashi, and Norihiro Sadato, National Institute for Physiological Sciences, Japan	*079*
	Study Implication Related to Sense of Acceptance: Key Factor of Social Learning	

12:00–12:55	Kei Mizuno, RIKEN Center for Molecular Imaging Science, Japan	*082*
	Neural Substrates of Motivation to Learn and Fatigue	

Closing Remarks	

13:15–	**Sayonara Party**

Conference Program

Poster Presentations

Note for the authors: The board available for each poster presentation is 90 cm wide and 210 cm high. Please submit your poster at the registration desk, and present it at the assigned core time. We request the authors to remove your poster before 17:00 on November 23.

Group A01: Palaeolithic Archaeology core time on November 19 & 20

Group A02: Hunter-Gatherer Studies core time on November 19 & 20

Poster Presentations

Group B01: Evolutionary Models core time on November 22 & 23

Poster Presentations

Group B02: Climate and Geoscience core time on November 22 & 23

Poster Presentations

Group C01: Skull and Brain core time on November 22 & 23

Poster Presentations

Group C02: Neuroscience

Keynote

Oral Presentations

The Opening Keynote ● Lectures

Neanderthals and Modern Humans – A Global View: Isolation, Expansion, Competition and Demise

Ofer Bar-Yosef

Department of Anthropology, Harvard University, USA

Neanderthals, a European population that emerged some 400-200,000 years ago (or earlier around 600-400,000 years) was undoubtedly successful in surviving through several glacial periods. The remains of their past life ways include human fossils (buried or not), food refuse (mostly bones, rare plants), preserved hearths in particular climatic conditions (such as the Mediterranean basin), and often plenty of stone tools. The information, published in more than one language, was collected through the excavations of numerous sites since the mid-Nineteen century. The Neanderthals are generally considered as Europeans who lived through the period we call "Middle Paleolithic", a relative chronological term formed prior to the time when radiometric techniques for dating were not available.

The Neanderthals possibly lived in small communities that were spread over large territories but maintained their relationships in order to keep their mating systems and secure their biological survival. When viewed through the few published samples of ancient DNA or their teeth across Eurasia, it seems that they represent a particular population. Morphological deviations from the western European Neanderthals were generally found at the edges of their spatial distribution.

Neanderthals emerged from what paleoanthropologists call *Homo heidelbergensis* and following their expansions into the Mediterranean basin as well as further east, reaching the Altai mountains, they interacted and mixed with other people, perhaps the direct descendants of the Asian *Homo erectus* who inhabited these lands in earlier times.

We often identify the Middle Paleolithic stone tool assemblages based on technological (various core reduction techniques) and typological aspects (*i.e.*, blanks that were shaped into tools). Among the latter archaeologists define side scrapers and points, shaped by retouch, some of which were constantly resharpened. Special types are large and small handaxes (considered as indicating cultural continuation from the earlier Acheulian Complex), and foliates. Their assemblages fall mainly under the categories of Mousterian of Acheulian Tradition and Eastern Micoquian. Using technological and typological traits, the Mousterian Complex was classified as a large entity by the mid-twentieth century, and one can geographically trace the Neanderthal "cultures" within this complex. Each recognized prehistoric "culture" is based on the assumption that the tool-kits are the technical expressions of people who kept manufacturing their traditional artifacts regardless of environmental fluctuations or even when they moved to a new area. For example, we can identify the bearers of two different stone tool making traditions, namely, the Eastern Micoquian with the foliates and another with Levallois convergent points, who camped in the same area of the Altai mountains. The evidence for their presence there was demonstrated by the discoveries of lithics, fossils and ancient DNA. However, the recent surprise brought by this type of biological analysis in the Altai was the discovery of an unknown population called the Denisovans. Thus, if we assume that the correlation between the fossils and the lithic industries is rather simple,

now, as archaeologists we challenged to uncover the culture of the Denisovans, who biologically emerged, as the current interpretation suggests, from *Homo heidelbergensis* but later than the Neanderthals.

Indeed, we already encountered a similar issue when the study of Middle Paleolithic fossils in the Levant took place from the 1930's onward. The Levantine Mousterian Complex of this region is currently divided into three industries, often uncovered in a stratigraphic order, from about 220/250,000 through 50,000 years ago, and are known as "Tabun D-type, C-type and B-type" or as Early, Middle and Late Levantine Mousterian. Various methods of Levallois technique characterize the Middle and Late Mousterian industries. The assemblages of the Late Levantine Mousterian, rich in Levallois triangular points, contained burials and isolated fragments of local Neanderthals (*e.g.,* Dederiyeh, Kebara, and Amud caves as well as layer B in Tabun cave). These fossils differ slightly in their skull morphology from the "classical European Neanderthals". The main surprise occurred already in the 1930's when the fossils uncovered with "Tabun C-type" (Middle Mousterian) artifacts in well arranged graves in Skhul and Qafzeh caves, were classified as a type of Archaic Homo sapiens, once even labeled as "Proto-Cro-Magnons" and considered until the early 1980's as the ancestors of modern humans. Perhaps they were, but further discussion is beyond the scope of this presentation.

Hence, the expansion of the Neanderthals into western Asia is fully supported by the Levantine fossils (dated to post - 80/70,000 years ago) and include those uncovered in Shanidar cave in the Zagros mountains (northern Iraq) and the skull fragment found in Sakjia cave, in the southern foothills of the Caucasus, as well as the human burial in Mezmaiskaya cave (Russia). The human groups who occupied the Taurus, Zagros and southern Caucasus mountain areas made industries rich in retouched pieces (scrapers and points). They differed from the sites on the northern slopes of the Caucasus, represented by the finds from Mezmaiskaya cave, where the tool kits contained the small bifaces or foliates and were part of the Eastern Micoquian

known from the European plains. Further east the Neanderthals are found in Uzbekistan, Siberia and their industries near the Yellow River. It is hypothesized that Neanderthal remains (or perhaps the Denisovans) should be expected in northern China. Therefore, in a few cases we already recognize territorial boundaries of Neanderthal groups (cultures? tribes?) across Eurasia.

The appearance of the modern humans is now suggested to have occurred around 60-50,000 years ago and there are no doubts about their African origins or the few paths they took as they migrated into Eurasia. We often attribute to modern humans a series of cultural traits although not all were a real cultural "package" and a few emerged in Africa during earlier period. These include high degree of mobility, sings for group identity, and use of ornaments. Thus moderns were capable of symbolic behavior that is expressed in the Franco-Cantabrian region by cave art, mobile art objects (also in other regions), and in a few localities by open-air rock art. Among their domestic activities scholars often cite the use of fire and stones for warmth banking, higher efficiency in hunting, evidence for feasting, and more. Among the lithics we stress the blade making which requires much less skill than producing Levallois products. But we should mention that not all modern humans made blades as for example the colonizers of Australia some 45,000 years ago who produced flake tools (while blades arrived there only in the Holocene). Not all modern humans groups shared artistic expressions. Similarly shell beads that already were shaped in a few Middle Paleolithic sites, were not common in all Upper Paleolithic contexts.

In reviewing the interactions between the two populations we should take into account the continental-wide archaeological information concerning the lithic industries of local Neanderthals. The best records are available from all over Europe as well and western Asia.

During the Upper Pleistocene Neanderthals in temperate Europe responded to climatic calamities by shifting and expanding their territories into western and central Asia. They were undoubtedly successful survivors as the recently published information

concerning the Campanian volcanic eruption in Europe demonstrates. Years ago we noted that during the cold period of MIS4 (*ca.* 75-57,000 years ago) Neanderthals in the north European plain moved into refugia in southwest and southeast Europe resulting in the depopulation of a large region in the northern latitudes. Hence, contrary to the prevailing view of several western European scholars during the last decade it was not the worsening conditions of MIS3 that caused the Neanderthals demise but the activities of modern humans - the new migrants.

Unfortunately, not all archaeologists and paleoanthropologists are familiar with the changing patterns of behavior of hunters-gatherers, or with issues of human reproduction. Foragers have three options when they encounter newcomers in their territory. They can greet them friendly and even biologically mix with them, ignore their presence or try to deter them physically from exploiting their traditional resources. Genetic evidence indicates that a certain degree of interbreeding did occur and thus all recent Eurasian populations bear Neanderthal genes. None of the African people have them and thus it becomes obvious that the mixing took place in this continent. There is some archaeological evidence to support it in the records of the so-called "transitional industries" (from the Middle to the Upper Paleolithic) although not all are "transitional" in the sense of cultural continuity. Hence, the long period of isolation, at least in the European region of this vast continent, Neanderthals became gradually extinct. A possible explanation is the effects of being cut-off the best territories for hunting and gathering due to their occupation by modern humans. The taking over certain critical terrains by the new migrants severed the long distance breeding networks of the Neanderthals. Reduction of the total fertility rate, for example, would naturally lead to the disappearance of "tribal populations". In addition we should consider the possibility of physical conflicts. Thus, Neanderthal groups became extinct some faster and earlier chronologically than others, while modern humans thrived.

Reference

Bar-Yosef, O. (2011) A geographic overview of Neanderthal-modern human encounters. In: *Casting the Net Wide: Papers in Honor of Glynn Isaac and His Approach to Human Origins Research*, edited by J. Sept and D. Pilbeam, pp. 193-212. American School of Prehistoric Research Monograph. Oxbow Books, Oxford.

Figure 1. The expansion of the Neanderthals.

Figure 2. The Neanderthal retreat across Europe.

Exploring Cultural Niche Construction from the Paleolithic to Modern Hunter-Gatherers

Nicole Creanza, Laurel Fogarty, and Marcus W. Feldman
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Niche construction is an evolutionary process through which organisms modify their environments, thereby altering the selection pressures on future generations. Cultural niche construction theory concentrates on those changes made by the spread of socially learned traits or to the evolutionary niche in which these socially learned traits evolve. Here we aim to use a model of cultural niche construction to elucidate the possible role of culture in the replacement of Neanderthals by modern humans.

We focus particularly on two important features of human populations: cooperation and teaching. We find that in a cultural niche construction framework, the presence of teaching enables beneficial innovations to spread faster and more easily, making them more likely to fix or persist in a population. This may provide a selective advantage over species unable to teach or who transmit information with less fidelity than modern humans.

Finally, we show that strong, high fidelity information transmission in early modern humans could have enabled cooperative hunting and meat-sharing practices to persist in a population where otherwise they would not. We hypothesize that the group-level benefits of cooperation and meat sharing could have given modern humans an advantage over similar species incapable of these practices.

Neanderthals and Modern Humans – A Cognitive View: Intelligence, Symbolism and Language

Steven J. Mithen
University of Reading, UK

Ever since the skeletal remains of Neanderthals were first discovered and debate began about their evolutionary relationship to *Homo sapiens*, speculation has occurred about their cognitive and linguistic abilities. Dramatically contrasting interpretations of the same archaeological evidence have been forwarded, positing Neanderthals as either having a radically different, and for some inferior, form of mentality than that of *H. sapiens* or having precisely the same cognitive capacity with regard to both intelligence and language. Those archaeologists who refute any differences in cognition invoke contrasts in environment, demography and/or society to explain any dissimilarity in the archaeological records of *H. neanderthalensis* and *H. sapiens* and, ultimately, why the latter remains extant today and the former is extinct.

This debate has recently been enlivened by claims for new evidence for Neanderthal symbolism, adding to those which have been long proposed but contested by those archaeologists who dispute Neanderthals were able to think and behave in a symbolic manner. In this paper I provide a critical summary of the debates and challenge the view that there is indeed a meaningful opposition between cognitive and environment/demographic explanations for differences between *H. neanderthalensis* and *H. sapiens*. This dichotomy fails to grasp the essential plasticity of the human brain – whether of a *H. neanderthalensis* or *H. sapiens*.

When viewed at a coarse and long-term resolution, there are three features of the archaeological record that have led some archaeologists to invoke cognitive differences between *H. neanderthalensis* and *H. sapiens*.

First, despite more than 350,000 years of existence, the extent of cultural and behavioural innovation of the Neanderthals was limited. Throughout this period of time they remained as stone-age hunter-gatherers with a limited cultural repertoire. In contrast, within the last 200,000 years that *H. sapiens* has been in existence, this species has invented/discovered agriculture, created towns, civilisations, science and so forth. While such developments are primarily restricted to the last 11,600 years – during the relatively warm, wet and stable Holocene period – the Neanderthals also lived through similar environmental conditions without making any fundamental changes in their behaviour. Anatomical evidence suggests that Neanderthals were living in conditions of environmental stress; hence their apparent 'failure' to invent bows and arrows, sewn clothing, substantial shelters appears surprising if they had the same cognitive capabilities as *H. sapiens* who did indeed invent these as means of adaptation to changing environmental conditions.

Second, there is limited, if any, unambiguous evidence for the use of visual symbols by Neanderthals. Claims have been made and debated regarding that coming from Neanderthal burials, and indeed that burial itself might be a symbolic act. Who manufactured the Châtelperronian 'art' objects has been a particularly vociferous, but ultimately unresolved, debate while the most recent claims concern the use of pigments by Neanderthals. The dilemma such claims provides is that it is difficult to explain the scarcity and ambiguity of such evidence on the basis of archaeological preservation alone. Large segments of the Neanderthal archaeological record are indeed better preserved than that of *H. sapiens*, but within the latter evidence for symbolic behaviour are forthcoming. It is evident that symbolic communication plays a key role in the adaptation of *H.*

sapiens to challenging environments. Hence in light of the environmental stress that the Neanderthals appear to have experienced it is again surprising that they did not use symbolic communication more prolifically than appears to have been the case if they had the capacity for symbolic thought.

A third reason to argue for significant cognitive differences between *H. sapiens* and *H. neanderthalensis* is simply the fact that *H.sapiens* is extant and the Neanderthals are extinct – and not only the Neanderthals but all other members of the *Homo* genus that ever existed. The dispersal of *H. sapiens* from Africa at c. 50,000 years ago and their rapid colonisation of the Old and New Worlds is such a remarkable event that some overriding explanation is required: what could be so fundamentally different about this particular member of *Homo* that led to such a radically different pattern of behaviour to that of all its relatives and ancestors? Few, if any, suggestions have been forthcoming other than an enhanced cognitive capability, perhaps situated in language.

The counter evidence for cognitive differences between *H. neanderthalensis* and *H. sapiens* rests not only on the possible existence of symbolic behaviour by Neanderthals but on three further aspects of the archaeological and fossil record. First, the large brains and evolved vocal tracts of Neanderthals appear no different, in essence, to those of *H. sapiens*. Why would these costly adaptations exist if they were not delivering the same degree of advanced cognition? Second, despite a low level of cultural innovation, the stone tool technology of *H. neanderthalensis* was extraordinarily sophisticated. Third, *H. neanderthalensis* endured for an extensive period of time through a wide variety of challenging environmental conditions. Could they have possibly done so without the levels of planning and decision making as found among *H. sapiens*?

There are, therefore, contradictory strands of archaeological evidence regarding Neanderthal cognition and how, if at all, it differed to that of *H. sapiens*. It was an attempt to resolve those contradictions and bring archaeological arguments into line with those in neuroscience and psychology that I introduced notions of mental modularity. In my 1996 book *The Prehistory of the Mind*, I argued that

Neanderthals had a domain-specific mentality while *H. sapiens* possessed the capability for cognitive fluidity, the latter largely deriving from the use of spoken compositional language. Wynn and Coolidge later argued that the Neanderthals had a limited degree of working memory that constrained their ability at maintaining multiple ideas in their mind at the same time – which is in effect another description of an absence of cognitive fluidity.

While Wynn and Coolidge remained unspecific about Neanderthal language capabilities, my own view was that compositional language was absent. How could it be otherwise when spoken language is the motor for cultural innovation which is so evidently absent among the Neanderthals? That left unresolved, however, how Neanderthals communicated especially in light of their vocal tracts and large brains. To address this my 2005 book, *The Singing Neanderthals*, proposed that a sophisticated communication system was present that had a greater reliance in variations in tone, rhythm and pitch and a less reliance on words and grammar than does compositional language used by *H. sapiens* today (and presumably in the past).

The extent to which the domain-specific model for Neanderthal cognition remains viable in light of the recently claimed evidence for Neanderthals symbolism in the form of use of pigments will be considered. It will be argued that this and other models of Neanderthal cognition require a greater emphasis on neuronal plasticity. Indeed, the current archaeological debate between either cognitive differences between *H. neanderthalensis* and *H. sapiens* or differences based on population and society will be shown to be simplistic and indeed quite false. One of the key defining features of human cognition is the plasticity of the brain that occurs not only in childhood but also in adults: one simply can never exclude a consideration of cognition when trying to explain differences in behaviour whether within a species or between species. In this regard we must become more adept at discussing cognitive variability within both *H. sapiens* and *H. neanderthalensis*, which may enable some degrees of symbolic activity to be accommodated in the latter while maintaining significant cognitive differences between these species.

The Reconstitution of the Neanderthal Brain

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The brain is arguably one of the most complex organs that evolution has produced. Moreover, it is evident that our own brains stand out from those of our closest living relatives – the great apes – not only by their enormous size, but by their ability to produce an almost unlimited diversity and complexity of cognitive, linguistic, and technocultural behaviors. Yet the exceptionally large brains of our own species *Homo sapiens* are not unique in evolution. Our evolutionary cousins, the Neanderthals (*Homo neanderthalensis*), had brains that rivaled ours in size. Most notably, it appears that the large brains of Neanderthals and humans evolved along independent paths, at least for several 100,000 years.

Which evolutionary and developmental processes, and which selective and structural constraints, led to the evolution of these two "brainy" hominin sister species? Which brain functions did we and the Neanderthals collectively inherit from our last common ancestor? And how did Neanderthal brains differ from ours in development, structure, function, and cognition? To tackle these questions, we have to follow various lines of evidence, and apply a diversity of research strategies. – In this talk, we give an overview of the current state of Neanderthal brain research, and highlight major promises and limitations for future research in paleoneurology.

One major difficulty of paleoanthropology, and especially of paleoneurology, consists in the fact that most fossil specimens are incomplete, fragmented and distorted, and at least partially embedded in sediment. Before any biologically relevant analysis can start, fossil specimens must be reassembled from their isolated parts; taphonomic distortions have to be corrected, and missing anatomical regions have to be completed with the ultimate goal to infer the individual's morphology at the time of its death. Over the past decades, we combined biomedical imaging of Neanderthal fossils with sophisticated computer graphics tools to reconstruct a large series of fragmentary Neanderthal specimens, which document the development of this species from birth to adulthood (Figure 1). The endocranial cavities contained within these skulls – the so-called endocasts – now represent the material basis of Neanderthal paleoneurology (Figure 2).

Reconstructing Neanderthal endocasts marks the first step on the long way toward Neanderthal brains. Since brains do not fossilize, their morphology, and possibly their function, have to be inferred from the morphology of the endocast. The morphology of endocasts is highly instructive, as it provides information about brain size, shape and structure, which is relevant to infer patterns of brain development, structure and function. However, endocranial morphology does not immediately reflect brain morphology. For example, the form of the braincase is not only modulated by brain morphology, but also by the size, shape and orientation of the face relative to the braincase. Furthermore, the endocast surface does not provide an immediate picture of the brain surface, because the space between bone and brain is filled with meningeal tissue, cerebrospinal fluid and a wide variety of blood vessels and sinuses. These structures tend to interfere with, or blur potential imprints of the brain on the endocast.

To generate reliable estimates of the brain surface of

a Neanderthal from its preserved endocranial cavity, comparative data from living species are needed. Biomedical imaging methods such as CT and MRI now permit the acquisition of bone and brain data from the same subject, not only in humans but also in our closest living relatives, the chimpanzees and other great apes. We developed an array of endocast-brain mapping procedures, which combine computer-assisted fossil reconstruction with soft tissue reconstruction methods used in forensics. This approach now permit inferences on the size, shape and surface structure of Neanderthal brains.

Only very few Neanderthal individuals are available to document the decisive early phases of brain ontogeny, where slight differences in rates of growth and development produce significant differences in brain size at adulthood. The decisive information about these phases comes from the newborn Neanderthal from Mezmaiskaya Cave (Russia) and from the two 1.0 and 1.5 year-old children from Dederiyeh Cave (Syria) that have been excavated by a Japanese-Syrian team led by Professor Takeru Akazawa.

Our analyses show that the brains of newborn Neanderthals and humans were similar in similar size (400 ccm), but clearly different in shape. Similarity in size is likely to reflect similarity of developmental constraints in both species. One such constraint results from the fact that, during birth, the head of the fetus has to pass through the constricted pelvic outlet of its mother. In modern humans, neonate head dimensions closely match the dimensions of the maternal pelvis, which is a major cause of birth complications. Our computer-assisted reconstruction of the only fairly well-preserved female Neanderthal pelvis (the specimen from Tabun, Israel) indicates that Neanderthal mothers had a more spacious pelvis than modern human mothers. However, it appears that birth in Neanderthals was as complicated as in modern humans, because Neanderthal newborns had even larger heads than modern human newborns. This was a consequence of the peculiar shape of the Neanderthal braincase, and their comparatively large face already at birth.

Tracking brain growth trajectories from birth to adulthood shows that during the first two years of life Neanderthal brains grew substantially faster than those of modern humans. Interestingly, however, Neanderthals did not reach adult brain size earlier than modern humans, but on average, they had larger brains at adulthood. These differences have various implications for the life history of Neanderthals. At first sight, it appears that their fast-growing brains fit into the widely held picture that Neanderthals lived according to a "live fast – die young" scheme. However, from a wider comparative perspective, large adult brains imply a longer life and even slower reproduction than in modern humans.

The marked differences between Neanderthal and modern human endocranial shape indicate that there have been major species-specific differences in brain development before birth. Following the developmental trajectories of Neanderthal and modern human endocasts after birth indeed shows that these prenatal differences are carried over into differences from infancy through to adulthood. As mentioned, the relationship between the endocast and the brain is complex, such that any inferences on the structural and functional development of the brain have to be taken with great care. During the early 19th century, it was common practice among the "phrenologists" to infer personality traits from the individual shape of a person's braincase. While modern neurobiology has debunked this simplistic path of inference, paleoneurologists are still tempted to establish direct links between the endocast and the brain, inferring major differences in "higher" cognitive functions between Neanderthals and ourselves.

What, if anything, can then be said about Neanderthal brain structures, brain development, and ultimately about brain function and cognition? One possibility is to infer differences in cognition and behavior between Neanderthals and modern humans from the archaeological record, which, to some extent, reflects the "behavioral output" of their respective brains. However, it is difficult to tell apart intraspecific technocultural differences from species-specific differences. Another possibility is to widen the scope of paleoneurology, including living great apes as comparative species, and adopting the methodological toolkit of modern neurobiology. Magnetic Resonance

Imaging (MRI) now permits non-invasive acquisition of structural and functional brain data from human volunteers and anesthetized great apes. Furthermore, recent methods of genomics and transcriptomics permit investigation of the genetic networks that mediate brain growth and development. These methods have already yielded surprising insights into differences and commonalities between human and great ape brain development, structure and function, and into the genetic underpinnings of these differences.

Establishing structure-function relationships between the genome and the phenome is a dauntingly complex endeavor, especially if it is about brains. However, given our steadily increasing knowledge about the Neanderthal genome and phenome, it is a research path worth to be followed. Wherever Neanderthal paleoneurology will bring us in the near future, we have to keep in mind that this endeavor will influence our views on Neanderthal brains, and vice versa. Reconstituting the Neanderthal brain will change the way in which we think about the Neanderthals and about ourselves.

Figure 1. Reconstructing the early development of Neanderthals. (left: the Mezmaiskaya neonate; right: the Dederiyeh 1 child, with an estimated age at death of 1.6 years).
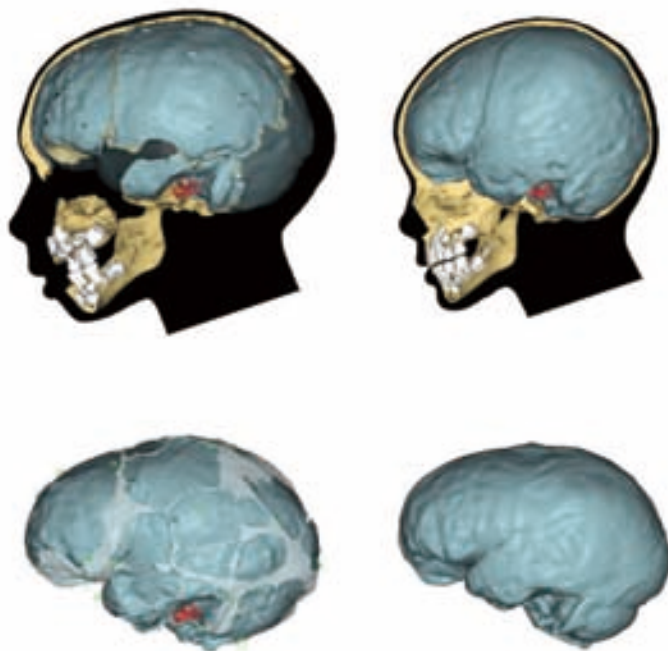
Figure 2. Endocasts of a Neanderthals (left) and modern humans (right). Top: the 4 year-old Neanderthal child from Devil's Tower, Gibraltar (left) and a modern human child with similar age (right; clinical data). Bottom: the endocast of the Le Moustier adolescent Neanderthal (left) and that of an adult modern human (right).

Oral Presentations

Oral

The Process of RNMH: Global and Comprehensive Explanatory Models
Learning Behaviors in Prehistoric and Modern Humans
Human-specific Learning Strategies and Cultural Evolution
Towards Digital Reconstruction of Fossil Crania and their Brain Morphology
Neuroimaging Approach to the Learning Hypothesis

The Replacement of Neanderthals by Modern Humans in Europe

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Over the last two decades of the 20th century, debates on the emergence of European modern humans and the fate of the Neandertals tended to revolve around the polar alternatives of "Multiregionalism" (in its original, strict formulation, implying that European moderns had evolved from local, ancestral populations of Neandertals) and "Recent African Origin" (in its original, strict formulation, defining modern humans as a new species with a birthplace in East Africa some 150,000 years ago, one that subsequently went on to colonize the rest of the world through a process of Out-of-Africa expansion in the course of which Eurasian archaic humans, namely the Neandertals, would have gone extinct without descent).

A minority position, the "Assimilation" model, accepted recent Out-of-Africa migration and/or genetic diffusion but viewed Neandertals not as a different species but rather as a geographically isolated Eurasian variant of *Homo sapiens* that ended up being assimilated in the wider human gene pool after 40,000 years ago as a result of demographic and/or natural selection processes operating in a context of significant population admixture. Paleontological, genetical and archeological research has shown such "Assimilation" views to provide the closest match to the revised and/or augmented empirical base concerning the replacement of Neandertals by modern humans gradually accumulated over the last 15 years.

Direct dating of the fossils that were thought to represent the earliest European modern humans — and, through their lack of anatomically archaic features, supported replacement-with-no-admixture of the aboriginal Neandertals — showed that they were all significantly younger, some times of recent Holocene age. Conversely, the newly discovered or restudied fossils dated to within five to ten millennia after the time of contact (e.g., the Lagar Velho child, the Oase 1 mandible, and the Oase 2 cranium) were all shown to present anatomically archaic, if not Neandertal-diagnostic features. These morphological mosaics were interpreted as indicating admixture at the time of contact and, despite much controversy, the Neandertal genome project eventually produced corroborating evidence; namely, that 1-4% of the genome of extant Eurasians is of Neandertal origin.

At the same time, archeological research provided evidence that, in the behavioral realm, late Neandertals had been as "modern" as their African contemporaries, thereby removing putative cultural barriers to interbreeding from the range of mechanisms that conceivably could have prevented admixture from occurring, while showing that some of the Upper Paleolithic innovations that "Recent African Origin" views interpreted as brought in by immigrating modern humans should in fact be credited to the Neandertals (namely, the use of pendants made of ivory, bone or tooth, as well as, possibly, the earliest, abstract/geometric cave paintings).

Cultural and Biological Transformations in the Middle Pleistocene Levant: A View from Qesem Cave, Israel

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In this presentation we provide our interpretation for the circumstances leading towards the evolutionary replacement of *Homo erectus (senso lato)* by a new hominin lineage in the Middle Pleistocene Levant, some 400,000 years ago.

In short, our hypothesis is that dietary stress caused by the disappearance of elephants triggered the extinction of *H. erectus*, a hominin species highly dependent of the consumption of calories from very large animals, and the evolution of a new hominin lineage that was better adapted to the new diet constraints of hunting larger numbers of smaller and faster animals in order to provide sufficient caloric intake to compensate for the loss of the elephants. The biological replacement took place in tandem with significant cultural changes and the appearance of a new, unique and innovative cultural complex in the Levant.

It is our contention that the appearance of a new and creative set of behaviors 400,000 years ago in the Levant must have been supported by innovative cultural transmission mechanisms, very different than the ones practiced during earlier Lower Paleolithic times. Advanced learning behaviors and abilities must have played a significant role in the adoption and assimilation of new hunting, meat sharing, flint procurement and flint production strategies, as well as in the earliest habitually use of fire. These new cultural traits characterized human existence in the Levant for a long period of over 200,000 years, to be later replaced again by the Middle Paleolithic cultural complex created by both *Modern humans* and *Neanderthals*.

H. erectus (senso lato) was present in the Levant during a period of over one million years, between 1.4 my and 400,000 years ago, and created the Acheulian cultural complex. We suggest that during this long period of time *H. erectus* was dependent on elephants (and especially their fat) for his survival.

The disappearance of elephants from the Levant some 400,000 years ago coincides with the end of the Acheulian complex and the appearance of a new and innovative local cultural complex – the Levantine Acheulo-Yabrudian. As is evident from the dental remains recently found in the Acheulo-Yabrudian site of Qesem Cave, the hominins occupying this cave were not *H. erectus* but were rather most similar to later Modern populations in the region (e.g., Skhul/Qafzeh). This hominin exhibits a new set of behavioral and cultural traits (e.g., habitual use of fire; meat sharing; innovative cutting tools; flint quarrying; lithic recycling etc.). Archaeological evidence world-wide seems to associate *H. erectus* with large and mediumsized game, most conspicuously elephants whose remains are commonly found at Acheulian sites throughout Africa, Asia, and Europe. In some instances elephant bones and tusks were also transformed into shaped tools, specifically artifacts reminiscent of the characteristic Acheulian stone handaxes. In Africa, *H. sapiens* appears around 200 kyr ago, most probably replacing *H. erectus* and/or *H. heidelbergensis*. Early African *H. sapiens* sites are devoid of elephants. The presence of elephants in many African Acheulian sites and their absence

from later Middle Stone Age sites evoked an overkill hypothesis, which was never convincingly demonstrated. Thus no link was proposed, in the case of Africa, between human evolution and the exclusion of elephants from the human diet, and no evolutionary reasoning was offered for the emergence of *H. sapiens* in Africa. We suggest that the disappearance of the elephants, created a need to hunt an increased number of smaller and faster animals while maintaining an adequate fat content in the diet, and this was the evolutionary drive behind the emergence of the lighter, more agile, and cognitively capable modern hominins in the Levant.

Qesem Cave is a Middle Pleistocene site in Israel, dated to 420,000-200,000 years ago (Barkai et al., 2003; Gopher et al., 2010) and assigned to the the Acheulo-Yabrudian cultural complex (AYCC) of the Lower Palaeolithic Levant. The cave reveals a rich and well-preserved array of lithic and faunal remains as well as human teeth. It provides a good context in which to test hypotheses concerning the intriguing liaison between the environment, culture, and biology. Here we summarize a decade of research suggesting that the unique cultural transformation seen at Qesem Cave might actually be related to local human evolutionary processes and the appearance of a new hominin lineage.

As attested at Qesem Cave, the AYCC is a unique, local cultural entity clearly differing from the preceding Acheulian and the proceeding Mousterian. It shows a suite of innovative behaviors including: the habitual use of fire; hearth-centered activities and functionally distinct activity areas; sophisticated raw material acquisition (flint quarrying); intensive and systematic blade production employing an efficient, innovative, and thoughtful technology; a noticeable presence of 'ahead of their time' Quina scrapers; and intensive flint recycling activities.

The 9.5 m stratigraphy of Qesem Cave offers a detailed background of sediment deposition that occurred as the karstic chamber cave was aging. Various environmental proxies correlate with global climatic timelines (stages 11-7) and more specific data reveal the dynamics of a changing ecology within generally Mediterranean regimes of forest vegetation zones.

Cave inhabitants hunted cooperatively, bringing body-parts of fallow deer back to the cave, which were then butchered, shared, and – as evidenced by the use of fire throughout the cave's 9.5 m deep stratigraphy and the many burnt bones – eventually barbecued (Karakanas et al., 2007; Stiner et al. , 2009, 2011). Abundant cutting tools were systematically produced at the site, most significantly flint blade knives made by an innovative and thoughtful technology (Barkai et al., 2005, 2009; Shimelmitz et al., 2011). Our lithic analyses and the study of use-wear signs on flint artifacts indicate a set of cutlery manufactured to handle the different stages of butchering, defleshing, and meat cutting (Barkai et al. ,2010; Lemorini et al. 2006). A study of dental remains (Hershkovitz et al., 2011) indicated that the hominins inhabiting Qesem cave were not *H. erectus* but rather most similar to later modern populations (e.g., Skhul/Qafzeh) of this region, notwithstanding some Neanderthal affinities as well. Based on a bio-energetic model it was recently suggested that the biological and cultural developments attested at Qesem Cave occured in the Levant some 400,000 years ago as an adaptation to new dietary constrains caused by a faunal turnover that led to the exclusion of elephants from the human diet (Ben-Dor et al., 2011). These results are consistent with the recently published innovative model for the evolution of the human Pleistocene populations of Europe (Bermúdez de Castro and Martinón-Torres 2012), suggesting the Levant as the Central Area of Dispersals of Eurasia (CADE), an "origin region" for human species biodiversity. Acknowledging we are challenging a well-established paradigm, our (as yet) insufficiently comprehensive hypothesis is offered with the intention of opening new vistas for discussion.

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Figure 1. Location map of Qesem Cave.

Figure 2. Excavations at Qesem Cave during the 2011 field season.

Figure 3. Flint blades from Qesem Cave.
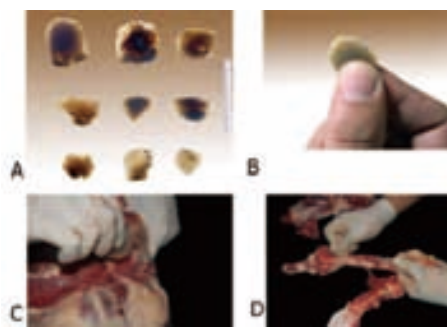
Figure 4. Butchering experiment using replicas of recycled small flakes from Qesem Cave.

From the Beginning: Tracing the Patterns of Cultural Changes of Early *Homo sapiens* in Africa, West Asia, and Europe

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This paper derives from our archaeological investigations on prehistoric learning behaviors, particularly those involved in anthropological processes of the replacement of Neanderthals by modern humans (hereafter RNMH). As part of the studies conducted by Research Team A01 of the RNMH project, we have been compiling archaeological data relevant to the RNMH process under two purposes. The first is to collect and organize updated material evidence regarding the RNMH in a comprehensive manner, and the second is to obtain insights into prehistoric learning behaviors through the observation of diachronic and geographic patterns of cultural variability. Using part of the archaeological database compiled since 2010,

i.e., the beginning of the RNMH project, this paper examines chronological and geographical cultural variability during the Middle and Later Stone Age (hereafter MSA and LSA respectively) in Africa and the Middle and Upper Palaeolithic (hereafter MP and UP respectively) in west Asia and Europe, and then discusses some implications of this archaeological evidence on the learning behaviors by early *Homo sapiens*.

The temporal and spatial range covered by the database of this project is set from ca. 300 to 20 kya in Africa and Eurasia, which is broader than those directly related to the RNMH events *per se*. This is because our aim is not just to trace the timings and frontiers of the RNMH events on the *a priori*
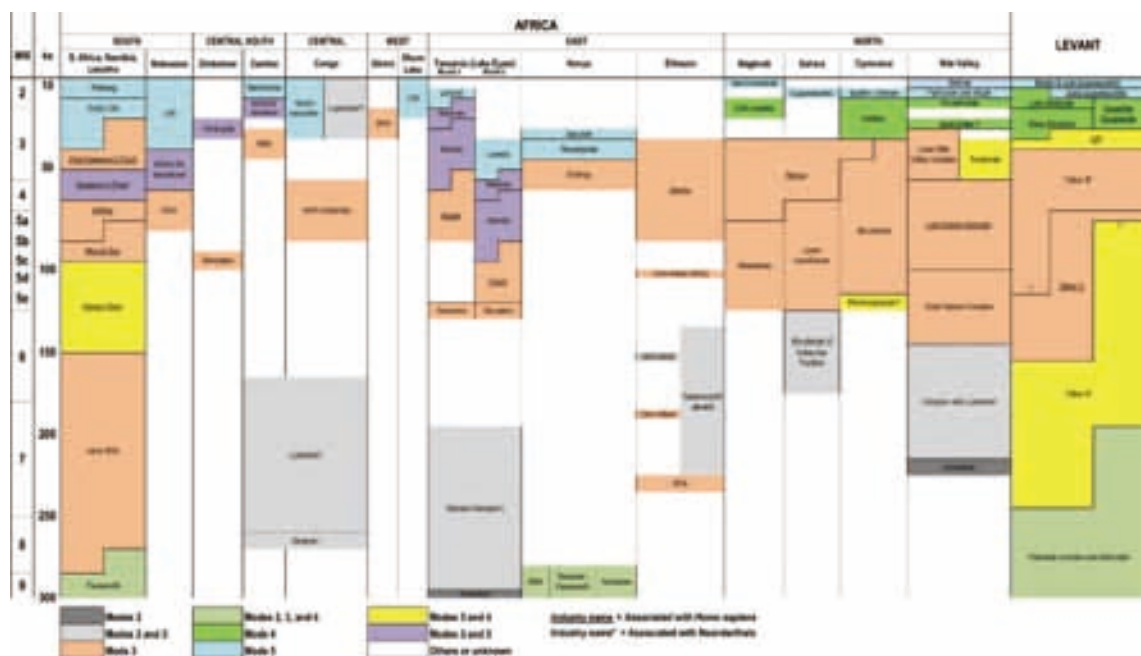
Figure 1. Cultural chronology of the MSA and LSA in Africa and the MP and UP in West Asia and Europe. Colors of cultural units indicate general technological characteristics (Clark's technological mode) of constituent lithic assemblages.

assumption that such anthropological events are directly reflected in archaeological records, but to organize archaeological data available from the time periods and geographic areas, where modern humans presumably emerged and dispersed with probable replacement of preceding populations, including Neanderthals. Because much remains to be clarified in the association between archaeological remains and hominin taxa, we put more emphasis in this study on the systematic presentation and assessment of archaeological data broadly related to the RNMH process rather than attempting to provide definitive archaeological answers to anthropological problems of the RNMH.

On the other hand, the broad temporal and spatial ranges of our archaeological investigations are also expected to provide us with sufficient size of data to examine diachronic and geographic cultural variations by modern humans and other preceding hominins, particularly Neanderthals. This analysis is intended to help us draw some implications on prehistoric learning abilities/ behaviors, which constitute the main research theme of the RNMH project that hypothesizes the differences in learning abilities/behaviors between Neanderthals and modern humans. Although theoretical links between learning strategies and patterns of cultural changes are proposed on the basis of cultural evolutionary theories, an attempt for their empirical testing entails a number of challenges. First of all, archaeological remains that can be securely associated with hominin taxa are limited. Moreover, it is difficult to reliably assess the speed and cumulativeness of cultural changes, which are considered significant aspects in the cultural evolutionary theory studied by Research Team B01 of the RNMH project, because of numerous chronological issues and variable definitions of prehistoric cultures. Because these challenges cannot be readily resolved, the present study would rather address and clarify these problems through empirical examinations of chronological and geographic distributions of archaeological cultures. We will then propose parsimonious interpretations of the patterns of cultural changes during the MSA and LSA in Africa and the MP and UP in west Asia and Europe in terms of prehistoric learning behaviors by early *Homo sapiens* and Neanderthals to contribute to the RNMH project.
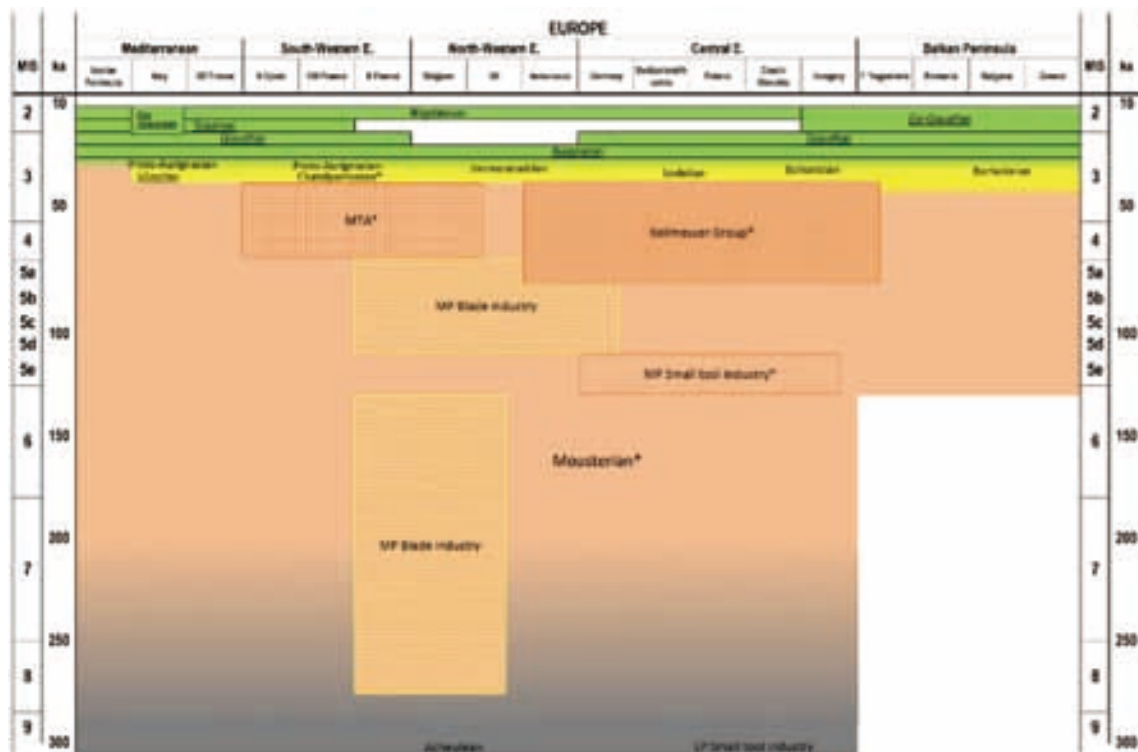
Figure 1 (continued).

Thinking the Beginning of Early Upper Paleolithic in Siberia and Central Asia

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The aim of this report is to provide an overview of the Early Upper Palaeolithic cultural complexes in the Northern Eurasia region where Neanderthal and *Homo sapiens* both had invaded from outside areas and achieved development and evolution of their cultures.

We will examine the background of the Early Upper Palaeolithic cultural formation processes based on paleo-environmental conditions and their cultural characteristics. As next step, we compare and consider formation processes of the Upper Paleolithic by tracing the aspects of Midle to Upper Palaeolithic transitions.Especially, we focus on the following 4 regions where provide some important achievements nowadays; Ural Mountains, Altai mountains, Central Asia and the Baikal Siberia. Using as basic data from our "NeanderDB" still in progress building by us, this study investigates some hypotheses and demonstrates notably viewpoints and additional new discoveries and other information.

Aspects of our basic materials are as follows:

(1) At present, the paleoanthropological materials have concentrated on the Altai mountains region. The human fossils from the Denisova and Okladnikov caves suggestthat there were three human populations in the MP-UP transitonal period; *Homo sapiens*, the Neanderthals, and the Denisovians, paleoanthropologcaly and meroculargeneticaly. While in the Central Asia, some paleoanthropological materials were also found and they have certain importance to traces of the Neanderthal's migration to the Southern Siberia, and they also had effects on the molecular genetic data.

(2) The archaeological materials suggest the repeated invasion from West: the Pebble tool cultures, Keilmessar groups, and Eastern Gravettian in the Ural Moutains. On the other hand, at the Altai mountains, after the invasion by Mousterian people during around 300 ka, the hypothesis of local technological development of litihic industries and gradual transition from Middle to Upper Palaeolithic have been insisted. In the Baikal Siberia (both of Cis and Trans Baikal) region, it seems that there were transitions from non-Mousterian local Middle Palaeolithic to Upper Palaeolithic, but its ancestries are still unknown. For considering distribution and ancestries of these Middle Palaeolithic cultures, it is notable to compare with Middle Palaeolithic aspects in the Central Asia, especially their chronological contexts as well as relationship between anthropological data and several variants of the Mousterian.

(3) As for the leaning behaviors, it had been pointed out that the elements of behavioral modernity such as potable arts (venus, figurines of animals), personal ornaments, and ochers, emerged in Northern Asia older than European regions. In our opinion, it will be important that to compare difference of site locations, hunting games, exploitation areas before and after the emergence of elements showing behavioral modernity. It would be necessary to create exceeding direct observation for the background of making
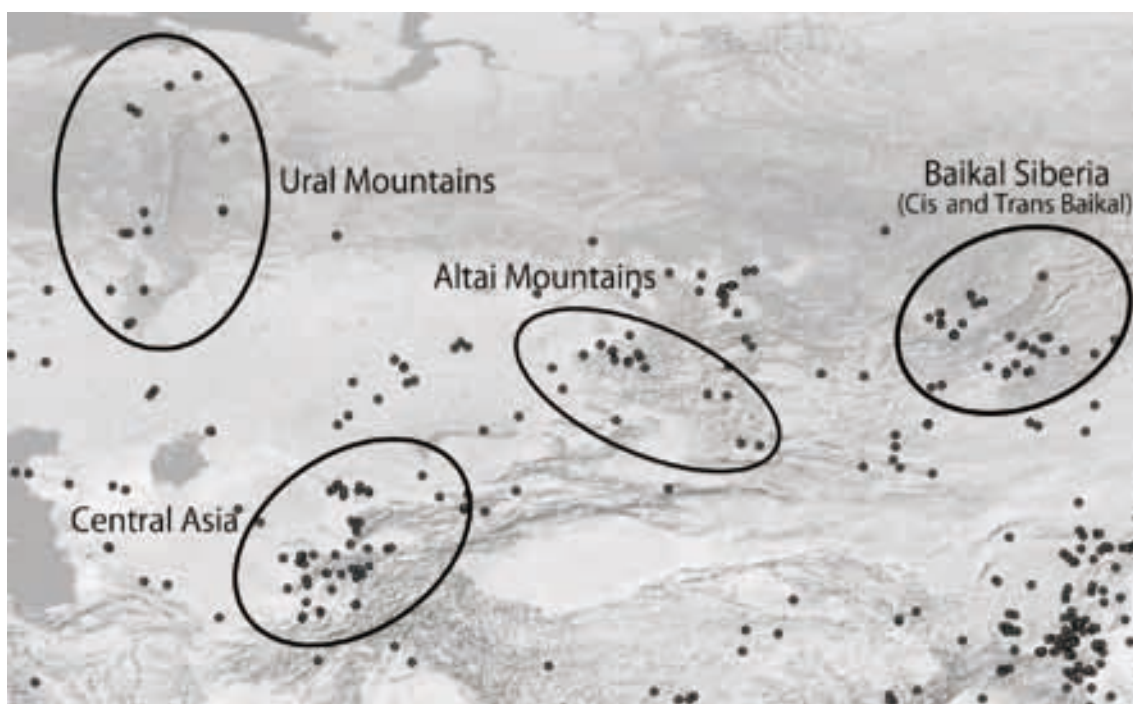
Figure 1. Distribution of the MP, MP-UP transitional, and EUP sites in Siberia and Central Asia.

animal designs. In addition, personal ornaments might be connected with the emergence of more complicated innovations on the sharing other groups and reciprocal alliance.

(4) As for the emergence of religions, the new discoveries suggest the burial contexts of Venus and animal figures; from Zaraisk and Mal'ta Upper Palaeolithic sites. If classical Upper Palaeolithic after 20 ka is defined by appearance of developing movement inner world as well as just living in actual world, the Early Upper Palaeolithic would be its infancy. The factors of the formation of spiritual cultures might suggest that unstable transitional period had drastically changed environment, culture and human population in Northern Eurasia.

Investigation of Past Climate and Vegetation for Understanding the Replacement of Neanderthals by Modern Humans

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The impact of climate change for the extinction of Neanderthal and other archaic human species related the dispersal of modern human (*Homo sapiens*) is intriguing but still challenging topic for archaeologists and anthropologists. There are several reasons why this is difficult to compare the climatic data from different kinds of media including ice cores, lake and ocean sediments and stalagmites, and the distribution of human species. In this project, we would like to contribute to provide some basic information for the temporal and spatial variability of climatic zones and ancient human species which could be recognized by different stone industries.

The temporal change of climate change was reconstructed from oxygen isotopic ratios in foraminifera from the benthic sediment cores, and oxygen isotope and other climatic proxies recorded in ice sheets from Greenland and Antarctic. That showed very drastic cycle of cooling and warming events in the late Pleistocene in which periods the modern human dispersed from Africa to Eurasia. However, the direct comparison between the events in human evolution and climatic events had been difficult because of dating methodology. The ice core data which are accepted as proxy of global climate change provide us more detailed temporal change such as Dansgaad-Oeschger events and Heinrich events clearly. The timing of each event are generally determined by counting annual rings recorded in ice core.

On the other hand, most archaeological dates regarding to the extinction of Neanderthal were determined by radiocarbon dating which is based on the reduction of radiocarbon from the "100% modern carbon" which fluctuate by change of the intensity of cosmic ray and geomagnetic field. Until recently, the fluctuation of radiocarbon activity in the late Pleistocene could not be estimated and the radiocarbon dates in this period theoretically contain several hundreds or thousands years uncertainties. By combining a series of data from marine cores and corals, the calibration curve for radiocarbon dates was expanded to 50 ka by Intcal09 dataset. This means we can compare the timing of events in archaeological records can be investigated in the history of global climate change at last. We are building a database of radiometric dates regarding to the extinction of Neanderthal and dispersals of modern humans in light of methodological evaluations. Some of key data must be taken away because of insufficient preparation and/or measurement. The selected data will give us more concrete and reliable map of distribution of different human species in time and space.

Second point which we have to overcome is the spatial variability of climatic and environmental conditions. As mentioned above, many geochemical proxies have showed the regional and global history of climate change in detail but the climatic map in that period is not easy to obtain for archaeological and anthropological discussions. For our project, one of authors heading a team of paleoclimatologists and geophysicists to make a series of climatic distribution maps to compare with the distribution of different human species. A coupled atmosphere-ocean general circulation model, named the Model

for Interdisciplinary Research on Climate (MIROC) was applied, which have produced results for the distant past including 6 ka, LGM of 21 ka, and mid-Pliocene 3 Ma. Some additional models for the growth of ice sheets and the dynamics of surface vegetation were also included.

Finally, we compare the results from the human distribution based on radiometric dating database and the simulated pale climatic maps in order to understand the climatic impact on the replacement of Neanderthal and other archaic humans by our species. For this purpose, we improve a ecological program for niche modeling. For example, we apply the MaxEnt program using maximum entropy model to see the suitable conditions including climate, geography and biozone for different human species. For applying this model, we use improved higher resolution (e.g., 60 km mesh) map for paleoclimate and the distribution of probability of calibrated radiocarbon dates. The preliminary results shows overlap and some differences in possible ecological niches between Neanderthal and modern human. We will investigate the temporal change of their suitable conditions in light of change in cognitive ability and/or way of life.

Cultural Transmission, Institutional Continuity and the Persistence of the Mousterian

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By all accounts Mousterian or Eurasian Middle Paleolithic material culture represents an extremely successful set of hominin adaptations. Mousterian technologies were used for more than 200,000 years by groups living in diverse habitats through several glacial/interglacial cycles. Yet they also disappeared surprisingly rapidly following the expansion of anatomically modern *Homo sapiens* into Eurasia. In fact, the same factors that underpinned the apparent success of the Mousterian technologies and culture may have hastened their eventual disappearance. Genetic evidence indicates that Middle Paleolithic populations, though widespread, were small and fragmented into numerous local demes. Middle Paleolithic foragers fed at a high trophic level, which would have facilitated expansion into empty habitats but also would have kept absolute densities low. These demographic conditions help explain the apparent continuity in Mousterian culture across great expanses of space and time.

Small, fragmented populations limit the rates at which innovations appear and spread and constrain the scale of random drift from ancestral states. At the same time, unstable populations inhibit the development of robust social networks and other cultural institutions that can store latent cultural information, a necessary pre-requisite to cumulative culture change. Equally important, it is difficult for dispersed, fragmented populations to resist invasion. Any cognitive or cultural characteristics which led to greater continuity in early *Homo sapiens* populations and cultural institutions would have helped them establish a permanent presence in Eurasia. The presence of invading groups would in turn have disrupted the already fragile social networks of Middle Paleolithic populations, disrupting lineages of cultural inheritance. Due to the more volatile nature of cultural transmission, the cultural heritage of indigenous groups was swamped even more quickly than their genes.

Evolutionary Development of Learning and Teaching Strategies in Human Societies

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As a team of cultural and biological anthropologists and developmental psychologists we aim at understanding the characteristics of learning behavior and learning strategies of modern hunter-gatherers through fieldwork to obtain clues to the replacement of Neanderthals by modern humans. We pick up the following three points as main fields of research: 1) hunting and gathering as a way of life, 2) children and childhood, and 3) children's play. These points are chosen based on the following ideas. First, we need to explore how people learn in hunting and gathering life that was the only lifestyle of humans during the replacement. Second, childhood is the most critical period for learning not only to get knowledge and skills for daily life but also to provide foundation for later development of innovative behavior. Third, in a society without school education, children learn mainly through daily activities, particularly playing in play groups. The following are some results of the study to the present time.

1. The long duration of childhood: Modern hunter-gatherers have a quite long childhood from infancy to adolescence and semi-adult in contrast to the Neanderthals who are said to have had only a limited period of childhood. During childhood children do not need to contribute to subsistence work and they can freely engage in play activities. Childhood is the time for brain development and definitely important period for learning.

2. During infancy, some innate learning process that responds to teaching behavior of adults begins, but from some time after weaning, children rarely receive direct teaching from adults. They leave their mothers or caregivers and join into play groups consisted of multiage children, where they learn various knowledge and skills through play. Particularly pretended activities such as play hunting are very important to obtain knowledge and skills not only for subsistence work but also to obtain an understanding of the nature itself. Nature affords the environment of learning with its diversity, complexity and dynamism which arouse much curiosity and desire for learning in children.

3. Children usually learn more by observing and imitating others on their own during play with other children than by receiving instructions from others. Learning through participation into communal activities is almost sufficient to obtain knowledge and skills for daily activities. Adults usually avoid giving strong instructions to children except for some occasions. This style of autonomous learning seems to foster creativity and adaptability in children.

4. Collage expression, picture drawing and Hand-Test carried out among the Baka children in Cameroon suggested their interests, creativity, attitude toward new experiences, and resilience, that is, the flexible attitude to difficult conditions. The cognitive flexibility was also suggested in children's object making activities. Psychological experiments for young children to investigate the

ability to comprehend visual signs and pictures showed their intuition and representation to signs and visual reception along with their flexibility.

5. Verbal instructions are not so much used for transmission of knowledge and skills as for social norms and values such as sharing, cooperation and friendly behavior. For those invisible things language is employed in various manners. Many metaphors are used in stories containing a variety of anthropomorphic images. Anthropomorphism, sometimes considered to be a primitive way of thinking, seems to be related to the development of various cognitive abilities and used as a unique and excellent method for representing world reality. Also ritual ceremony such as initiation rite works as an occasion to teach social values and morals that are rather difficult to teach only with verbal instructions.

6. During adolescence daily activity of young people, males particularly, increases very much in accordance with growth spurts of the body. They explore deeply into the environment and expand the scientific knowledge of nature, in particular, animals, plants and other things related to subsistence work and also obtain an understanding of how nature works. Young adults visit distant groups from time to time, one of the goals being to find a mate. Such a visit intensifies their social network and brings about an occasion for transmission of information and innovation.

7. The cultural innovation in hunting and gathering societies covers very wide domains from material culture such as foraging tools, clothing and housing to non-material items such as ritual, song, dance, play, and body decoration. Most of those innovations are not made individually in each group but transmitted from place to place. Innovation becomes recognized and fixed through transportation to other groups where it may serve to give birth to new ones. In modern hunter-gatherers innovation is not only related to individual ability to innovative behavior but also

closely connected to the social learning system.

8. The band, a daily living organization of hunter-gatherers, is characterized by flexible membership and fluidity. Bands are connected to each other by their social network. People frequently pay visits to relatives and friends through such networks to provide opportunities for the exchange of people and goods. Those extensive social networks and frequent movement of people make the base of cultural innovation. Comparison between Neanderthals and modern humans in terms of the range of people's mobility may help to consider the degree of Neanderthals' cultural innovation.

9. Cognitive sciences have revealed the importance of metacognition and meta-learning in modern humans. Our anthropological fieldwork also suggests the usefulness of "teaching without teaching" as a method of education. Metacognition and meta-learning presuppose higher cognitive ability and brain function. The large morphological difference of the brain between Neanderthals and modern humans suggests some important functional differences between them, one of which may be the difference of learning ability on the level of metacognition.

10. The evolution of learning ability depends not only on a single factor but on the synthetic development of various factors in the following three domains: cognitive abilities, knowledge about the nature, and social system. Investigation of learning behavior in modern hunter-gatherers so far suggests that factors in those three domains are interconnected and related to each other to create their unique learning strategy. Collaboration between anthropological fieldwork, developmental psychology, educational sciences, cognitive sciences and primatology should be continued to elucidate the nature of the human learning system.

Here we have a tentative sketch of the evolution of the human learning capacity:
(1) *Australopithecus* and other ape-men: Those

human ancestors were almost at the same level as contemporary great apes like chimpanzees and bonobos in terms of cognitive ability and subsistence skills. During this period they carried out social learning such as observation and imitation (emulation), but with slight cultural transmission between generations.

(2) *Homo erectus* and Neanderthals: There were social transmission of cultural heritage based on excellent social learning. In Neanderthals there also might be teaching behavior in order to reproduce the elaborate stone tools with almost the same shape for hundreds of generations. However, in this stage development of innovative behavior and social networks was minimal. Also the cognitive ability to handle the matter of metacognition seems to be insufficient.

(3) *Homo sapiens*: A big development took place in learning behavior due to the development of cognitive ability, in particular, metacognition. The knowledge on the nature expanded enormously and brought about the development of imaginative and symbolic thoughts. Flexible and creative individual learning along with rapid and accurate social learning produced a powerful learning strategy in modern humans. The development of social network and mobility of individuals brought frequent cultural exchange which led to further creation of new ideas and technology.

New Insights into the Skill Learning Processes in the Lithic Production: An Analysis of the Refitted Material from the Kyushirataki 15 Site in Hokkaido, Northern Japan

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Refitted portions of lithic tools and production debitage found together can be viewed as reflections of the past knapping activities carried out at a specific time, at the place of discovery. An analysis on the spatial patterning of the refitted materials may reveal the past human behavior involving the skill transmission process. If numerous pieces of artifacts including cores, blades or microblades, retouched tools, and debitage are successfully refitted, we can understand how the past stoneworkers operated and organized their actions along with technological choices and decisions, from the initial acquisition of raw materials, through tool manufacture, use, and discard (Bleed, 2002; Takakura, 2010). The study of lithic refitted materials, especially paying attention to a difference of the knapper's competence for lithic manufacturing, may provide rich information with regard to the skill expressed materially by the past knappers along with the operational sequences in the lithic production. Indeed, some of the Magdalenian open-air sites in the Paris Basin, France, have offered well-known case studies to make an attempt to address it (Bodu et al., 1990 and many others).

In Japan, there are a number of the refitted materials recognized in the Upper Paleolithic sites. Especially, the lithic refitted materials obtained from the Shirataki sites, Eastern Hokkaido, are unique in the Upper Paleolithic record in Japan. First, numerous refitted materials are recognized from each of the assemblages, having a wealth of technological information concerning the reductions of blades, microblades, bifaces, and boat-shaped tools respectively. It apparently enables us to compare the refitted materials within particular assemblages supposed to be an identical cultural tradition. The procedure of such comparison may prove a useful way of considering the unevenly expressed skill within certain assemblage, in order to explain the learning process among the past knappers. Second, several obsidian refitted materials, conjoining with many of stone tools and debitage, sometimes reconstructed nearly original raw material, are recognized. These materials can contribute to surmise the morphological features of gravel and lithic debris used as original raw material in the respective assemblages. Last, we can assess the spatial distributions of the refitted lithic artifacts within the respective sites, although these were to some extent modified by natural transformation processes such as solifluction. Analyzing these distributions is critical to answering the questions concerning the skill learning processes, highlighting how the distributions of the analyzed refitted materials relate to the prehistoric human behaviors occurred within site.

In this paper, I attempt to analyze the refitted materials obtained from the Kyushirataki 15 site, and discuss two topics mentioned below.
1) How the operational sequences of the past knapping were segmented in the progress of manufacturing and organized? Also, how can we understand it?
2) Did a shift of the knapper in the progress of operations happen? Also, how can we identify it?

Figure 1. Refitted material No.96 from the Kyushirataki 15 site. This shows that large debris of obsidian was used as raw material for blade reduction. The former stage of manufacturing was aiming to detach the large blades, with careful preparations and rejuvenations of core. In the progress of blade manufacturing, large blocks were gained by splitting and used as blanks for manufacturing of the boat shaped tools. After that, the small blades were detached from the diminished core again. These resulted in face battering and stacked steps on the flaked surface and platform of the core.
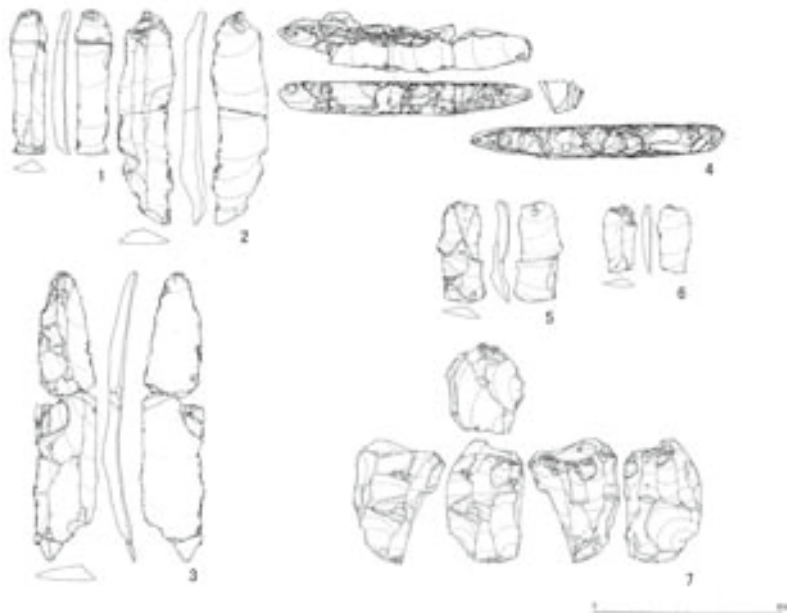
Figure 2. Artifacts included in the refitted material No.96. The Manufacturing stage of this refitted material can be divided from 1 to 34 (Naoe, 2012). 1-2: blades produced from the manufacturing stage 12, 3: blade produced from the manufacturing stage 14, 4: the boat shaped tool produced from the manufacturing stage 15, 5: blade produced from the manufacturing stage 23, 6: blade produced from the manufacturing stage 25, 7: discarded blade core

"Gift" as a Means of Cultural Transmission: An Archaeological Implication of Bow and Arrow Technology in Papua New Guinea

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Introduction

A primary goal of the research project RNMH is to investigate how the learning behaviors of Neanderthals and modern humans differed in regard to their archaeological records. The evidence currently being evaluated includes a combination of the material remains recovered from archaeological sites and the data obtained through approaches known as experimental archaeology and ethnoarchaeology.

In this paper, I will discuss an ethnoarchaeological approach that explores how observations related to a modern human society can be utilized to understand prehistoric learning behaviors. A case study will be presented using data collected in 1971 by Hitoshi Watanabe (1919–1998) on the bows and arrows belonging to a hunter-farmer's community in Papua New Guinea. Watanabe's innovative fieldwork strategy, named by him as the "bow-and-arrow census," documented detailed morphological data on all of the existing bows and arrows in the study settlement along with personal information about the individuals who manufactured and owned them. This unique corpus of data provides us with a rare opportunity to investigate the learning processes involved in bow and arrow manufacturing and the use of this technology in a pre-industrial society.

Watanabe's bow and arrow census data from Papua New Guinea

Watanabe's fieldwork was carried out at the native village of Wonie in western Papua New Guinea between July and August 1971. The village consisted of 16 houses/families, with a population of 103, including infants. The primary forms of subsistence of the village's inhabitants were hunting and farming (with men doing the hunting and women the farming); hence, they were hunter-farmers, or hunter-horticulturalists.

The uniqueness of Watanabe's research lies in its methodology. He collected census data on the population and the bows and arrows present in the village. The census data offer comprehensive information on sex, age, education, occupation, family, experience of hunting, etc., whereas the data on the bows and arrows include raw material, measurements, manufacturer, owner, and so on. Most of these data are presented in Watanabe's monograph (1975) and additional data can be obtained from the Hitoshi Watanabe collection that was donated to the University Museum, Tokyo, after his death (Nishiaki 2007, 2011). The latter collection includes original specimens such as arrows and bows, manufacturing tools, toy bows and arrows, video tapes, photos, and numerous written records.

Analysis

My research goal is to establish a model on the learning process behind bow and arrow technology. This model incorporates information on how an individual learns to make and use the bow and arrow, during his lifetime and how that knowledge is transmitted from one generation to the next. Data on the bows and arrows were analyzed in

relation to the age of their manufacturers and owners. Particular attention was paid to the ownership of each bow and arrow, since Watanabe emphasized the tradition of giving bows and arrows in the Wonie society. In addition, changes in the technological patterns of the bow and arrow by age group (e.g., infant, child, adolescent, adult, and elderly) were considered:

Using: what type of bow and arrow is owned by each age group; and what type of game is hunted by each age group.
Manufacturing: which age group makes which kind of bow and arrow; and the level of the manufacturing skill expressed by each age group.
Giving : the age group of both giver and recipient and the type of bow and arrow given.

Results

The analysis yielded the following observations. First, the learning of bow and arrow technology is domain-specific and it progresses cumulatively. The knowledge and skill of the manufacture and use of this technology, as well as the decorative style, do not develop simultaneously. For example, infants only use the bow and arrow during play, while children use them for capturing small animals such as birds and fish. Later in their childhood, they begin manufacturing their own bows. The manufacture improves during their adolescence, and when they reach early adulthood, all of the necessary elements involved in bow manufacture, use, and decoration are established.

Second, learning bow and arrow technology is part of a dynamic system. As in most hunter-gatherer societies, there is no evidence of teaching. However, the Wonie case suggests that their tradition of giving serves as a means of teaching. In nearly all cases, bows and arrows are given by older individuals to younger ones, with a few exceptions among the adult group, who exchanged products with one another. Younger individuals are given bows and arrows specific to their age group. When younger individuals age, they manufacture the same type of bow and arrow that they received

early in life and then give these items to the younger age groups. The knowledge of bows and arrows thus continues through cycles of giving.

Third, knowledge and technological skills of the bow and arrow differ among age groups. The most distinctive period involves adolescence, when the types of bows and arrows given to individuals vary the most. This suggests that adolescent individuals learn more during this period of their lives than the other age groups.

Implications for prehistoric archaeology

Watanabe noted the importance of giving or gift in cultural, sociological, and ecological terms. I would like to emphasize its importance in the teaching-learning system of a society. As a matter of fact, giving seems to play a primary role in the transmission of bow and arrow technology in Wonie society. While the motive behind giving was not specified in Watanabe's records, there was no obvious reciprocation between the giver and recipient. The scenario is probably comparable to what Mauss (1990) described on primitive society's giving tradition in the early 20th century. The gift of bows and arrows was made by the elders to the young individuals, who then reciprocated when they became older. This system cycled throughout a generation.

This gift-education model can serve as a guide for exploring differences in the learning behaviors between Neanderthals and modern humans and their consequences on the archaeological record. For example, the domain-specific progress in learning can be tested with careful analyses of the techno-typological features of the archaeological objects. In addition, the life histories of Neanderthals and modern humans can be examined from a biological point of view. Was adolescence in Neanderthals shorter in duration than in modern humans? Finally, was there any evidence of giving among Neanderthal societies? We have a lot of evidence of trade and perhaps also giving for the modern human sites, but little incontestable evidence exists in the archaeological record of the Neanderthals. If adolescence was

indeed shorter and there was no established tradition of giving, the learning of material culture in Neanderthal society likely differed significantly from that of modern humans as well as modern hunter-gatherers, such as the Wonie of Papua New Guinea.

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The Effects of Cross-Boundary Rituals on Cultural Innovation

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Introduction

In this talk, we attempt to test the hypothesis that the cross-boundary rituals, in which members of different groups communicate with one another, affected the development of the culture of modern humans. To test this hypothesis, we introduce an agent-based model (ABM) simulation. We then introduce case studies of residents of rural areas in Japan and Australian Aboriginal people to show how present-day modern humans performed cross-boundary rituals.

ABM simulation

To test what types of rituals are necessary for cultural accumulation, we build an Agent-Based-Model (ABM) simulation. The ABM assumes N agents and M groups. Culture consists of K independent traits, represented as the vector $(c_{i,1}, c_{i,2}, ..., c_{i,K})$ for agent i. If the agent knows or does not know the jth cultural

Figure 1. If agents migrate between groups (x > 0) and agents of many cultural traits lead cross-boundary ritual (0 < y < ∞) ,the average value of Σ c increases significantly.

trait, $c_{i,j}$ is 1 or 0, respectively. In the simulation, agents copy others' cultural traits within their groups as well as at cross-boundary rituals.

The simulations suggest that $\sum_j c_{i,j}$ swiftly increases if the cross-boundary rituals are held between agents of relatively many cultural traits and any agents migrate between different groups (Figure 1). The modern humans should have performed such cross-boundary rituals and migrated between groups to expand their advanced culture.

Japanese rural ritual

Traditional rituals, "spirit dances" or "kagura", continue to be performed in many rural areas of Japan. Recently, an increasing number of tourists visit kagura performances as audience members and the kagura performances have become the cross-boundary rituals. Some kagura performances are still within-boundary rituals in that kagura limit participation to local residents. Thus, to test the effects of cross-boundary rituals on present-day modern humans, we can compare kagura groups in terms of how they deal with tourists. The questionnaires were mailed to 155 leaders of kagura groups in Miyazaki prefecture; 87 (55%) of whom responded. Audiences for 49 groups were composed primarily of local residents (within-boundary rituals) and those for 39 groups consisted primarily of tourists (cross-boundary rituals). The number of dancers and audiences increased in 55 (active) groups and decreased in 32 (non-active) groups, respectively, for these 10 years.

The data suggest that in within-boundary rituals, members should limit participants to local residents

and recruit from their communities to activate their kagura. In cross-boundary ritual, in contrast, members should communicate with tourists and advertise their local communities. Furthermore, leaders of kagura performing cross-boundary rituals found that they could educate young dancers and experience kagura as a form of enjoyment in activated kagura. Accordingly, cross-boundary rituals affect the cultural accumulation of contemporary modern humans by enlivening kagura through communication with outsiders. Such mechanisms were likely to be operating during the age in which the replacement occurred.

Australian Aboriginal ritual

In northeastern Arnhem Land, in the Northern Territory the Yolngu language speakers live in four villages. The Yolngu still value many of their traditional practice especially their rituals. These rituals remain at the core of their social life and people devote considerable energy to them. Besides localized rituals, there are larger ritual festivals that not only bring members of many Yolngu clans together but people from other linguistic groups. On these occasions people may exchange their dances and songs. Through such festivals groups of distantly related people make alliances and trade.

There was the opportunity for wife exchange in some ceremonies where visitors came from far away. The organizers of a Kunapipi ceremony would send a messenger informing other groups that they planned to hold a ceremony. To do it in the correct way, the ritual intercourse had to be carried out with the consent of the female partner, which was essential if it was of not to cause conflict. Men intending to swap wives had to send presents via a messenger who was in a special relationship to the receiver. On the last day of the ritual, after the previous exchange of messages and gifts, the men got together at the camp site of the Kunapipi ceremony and sat in a circle, with women dancing in the distance, showing their willingness to accept intercourse by a feathered headband on their forehead.

Currently in Arnhem Land, those old sexual practices have been abandoned, although, Kunapipi rituals remain a focus of social life. So in the contemporary situation, the ritual still functions as an occasion for the transmission of traditional knowledge from old to young, and as an important occasion for socializing and exchanging of knowledge with people from distant places. And today because more people can come together by plane, boats and cars, it increases the opportunity of active cultural exchange.

Conclusion

Durkheim depicts the function of rituals as the intensification of sense of solidarity of the group. But as we have seen, ritual festivals are not attended only by the local population but are also attended by people from far away who do not interact on a frequent basis. The exchanges during the rituals opened up opportunities for knowledge exchange and were probably important sources of cultural innovation. They could also lead to intermarriage, migration and genetic exchange which increased the chances for stable cultural innovations.

Teaching, Trust, and Early Rapid Social Learning in Hunter-Gatherers

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Prominent cultural anthropologists Margaret Mead, David Lancy, and Barbara Rogoff indicate that teaching does not exist or is rare in small-scale cultures. By contrast, recent research by cognitive neuroscientists Gyorgy Gergely and Gergely Csibra indicate that one type of teaching, called natural pedagogy, is a human universal, part of human nature, and not found in the great apes. They hypothesize that this form of teaching emerges in infancy and that it enhances humans' ability to faithfully transmit "opaque" cultural knowledge, such the function of a particular tool. Learners evolved to pay attention to particular cues, such as eye and body movements, and teachers evolved the skills to convey important information to learners, such as pointing, using personal names, looking at or making sounds about important knowledge. Cognitive science research on natural pedagogy is limited because all of their studies have been conducted in laboratories with Western infants. This study uses videotapes of 10 Aka hunter-gatherer 12-14 month-old infants in naturalistic settings to evaluate the natural pedagogy hypothesis. The study shows that natural pedagogy exists in hunter-gatherers, but that it occurs relatively infrequently. The study also identifies two new forms of hunter-gatherer teaching that are rare or do not exist in the great apes—distributed teaching and opportunity scaffolding. These new forms of teaching occur more frequently than natural pedagogy and may have other social learning functions other than transmitting opaque knowledge.

The cognitive scientists also indicate that the ability to read the intentions of others (theory of mind) is not necessary for natural pedagogy to evolve, but that learning from natural pedagogy is much more likely to be efficient, early, and rapid if the learner trusts and feels secure with the teacher. The paper describes the contexts of infant and child development among Aka hunter-gatherers that promote trust and empathy in child development. The paper emphasizes how interactions between inherent evolved cognitive mechanisms, such as natural pedagogy, and contemporary hunter-gatherers' culturally constructed environments, amplified social learning and made cumulative culture a distinctive feature of modern *Homo sapiens*.

Determinants of Cultural Evolutionary Rates

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The "learning hypothesis" seeks to account for the replacement of Neanderthals by modern humans (*Homo sapiens*) in terms of an innate difference in learning strategies (abilities) between the two species. It comprises three proposals that form a "syllogism": 1. there is an innate difference in the learning strategies employed by modern humans and Neanderthals; 2. the difference in learning strategies translates into the observed difference in cultural evolutionary rates and cultural content between the two species; 3. the difference in cultural evolutionary rates and cultural content contributed significantly to the extinction of the Neanderthals and their replacement by modern humans.

Empirically, we know or suspect two things that are relevant to proposal 3. First, the stone tools made by modern humans, after say 50,000 years ago, underwent rapid changes compared to those made by Neanderthals. That is, there was a significant difference in the cultural evolutionary rates exhibited by the two species during the Paleolithic. Moreover, modern humans also had ornaments, art, and tools made of materials other than stone. Second, replacements of modern human ethnic groups by other modern human ethnic groups in historical times—notably the European expansions into the Americas—were driven by differences in the cultural content of the competing groups and by demographic differences contingent on the differences in cultural content. These observations suggest that, if Neanderthals and modern humans did indeed compete, the more culturally advanced modern humans would have prevailed.

Our research group, B01, has as its goal the theoretical justification of the learning hypothesis. Evolutionary theory cannot be used to prove proposal 1, i.e. the existence of innate differences in learning strategies. Research groups C01 and C02 will eventually provide archaeo-neurological evidence for size differences between modern humans and Neanderthals in the areas of the brain involved in individual learning and social learning. Meanwhile, evolutionary theory can generate predictions as to what kinds of learning strategies will evolve under given environmental conditions, more specifically under given patterns of temporal and/or spatial environmental variability. Then, in combination with the empirical data provided by research group B02 on the environmental conditions experienced by modern humans and Neanderthals, which presumably were different, we can plausibly argue for an innate difference in the learning strategies of the two species.

The specific theoretical question that I ask in this paper is: how does a learning strategy determine the cultural evolutionary rate? That is, I will be addressing proposal 2 of the learning hypothesis in my talk, interpreting this as a statement in logic. Before doing so, let me define what is meant by a learning strategy. Its components are individual learning (i.e. learning from personal experience, e.g. by trial-and-error) and social learning (i.e. learning by copying others, e.g. by imitation). A learning strategy is the way in which individual learning and

social learning are combined, either simultaneously or sequentially, and the relative dependence on each. The modes, pathways, and biases of social learning are also integral components of a learning strategy. Using these terms, a short definition of cultural evolution is: the spread through social learning of innovations produced by individual learning.

In this paper I discuss two theoretical studies showing that the innovation rate contributes most strongly to the cultural evolutionary rate. Since a higher rate of innovation requires an advanced aptitude for individual learning, this argument entails that Neanderthals were relatively deficient in individual learning compared to modern humans, whereas they were equally adept at social learning. Other researchers have argued for the importance of modes, pathways, and biases of social learning, such as "one-to-many" social transmission where one expert serves as the teacher to many novices, and "direct bias" where the individual with the "best" variant of a cultural trait is identified and copied. Demographic parameters such as the total population size and the number of acquaintances have also been invoked. The relevance of such factors is also an empirical question that needs to be resolved by research groups A01 and A02. Theoretically speaking, however, they are not as important as the innovation rate in determining the cultural evolutionary rate.

Definition and analysis of the cultural evolutionary rate utilizes the analogies between genetic (i.e. biological) evolution and cultural evolution. For example, when long-term changes in many cultural traits are under consideration, we can adapt the infinite sites model of population genetics, yielding the formula

$$R = \sum_{i=1}^{m} N_i u_i \pi_{1i}$$

for the cultural evolutionary rate. Here, m is the number of social roles (e.g. male and female, age classes, expert and novice), N_i is the number of individuals in social role i, u_i is the innovation rate of an individual in social role i, and π_{1i} is the fixation probability of an innovation made by an individual in social role i.

One application of this formula is to the question of whether one-to-many social transmission will accelerate cultural evolution, as has been proposed by some archaeologists and anthropologists. Based on a simple model, I show that one-to-many social transmission per se has no effect on the cultural evolutionary rate.

Scheduling of Individual and Social Learning as Optimal Life History Strategy

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In the replacement of Neanderthals by modern humans, innovative stone tools produced by modern humans might have played an important role. Advanced and complex industries can never be invented by a single individual without learning from other individuals. They are results of cumulative cultural evolution in which knowledge is inherited from parental generations to offspring generations. However, if all individuals simply copied what had been already known, there would be no advancement in technology. Contribution to the culture by improving the preceding knowledge, such as a discovery of new adaptive use or form of stone tools, is also crucial for cultural evolution. Inheritance of culture is realized by social learning and improvement is realized by individual learning. Thus, it is an important problem when the cumulative culture develops fastest under different learning strategies: when and how should an individual perform learning in one's life?

The balance between a weight assigned to learning and a weight assigned to the exploitation of the learned knowledge is also an interesting problem. To maximize the accumulation rate of culture, one should spend sufficient time to absorb the existing knowledge in the parent generation and then spends the rest of one's lifetime to improve the knowledge by individual learning. However, such a learning schedule does not necessarily maximize the fitness of the focal individual, i.e., the expected number of biological offspring. Possible scheduling of social learning, individual learning, and the exploitation of the knowledge is illustrated in Figure 1.

These types of problems have been studied in the field of behavioral ecology and referred to as the optimization of life history strategy. Several mathematical frameworks such as Pontryagin's maximum principle or dynamic programming are known. A famous example is the optimal schedule of allocation of resource into growth and reproduction in plant's life history.

Recently, some researchers have applied these frameworks (optimal scheduling) to study cultural evolution. Conceptually speaking, this question had been already considered in the model of Social Learning Tournament. After a brief (and non-mathematical) overview of the previous studies, we will introduce some of our recent results on optimal learning schedule based on mathematical modeling and analysis. We find that social learning and individual learning occurs in this order in the evolutionarily stable schedule. This order is consistent with the one necessary for cumulative cultural evolution (because otherwise modification or improvement to pre-existing knowledge does not occur.) We also find that the maximization of personal fitness greatly contradicts the maximization of cultural level of a whole population. That is, even though much higher level of culture can be sustained if people spend some more time in learning, the competition between individuals does not allow a population to reach this level. The situation is somehow similar to a public goods game where public goods represent the level of culture of a whole population. Our

results provide a basis of a working hypothesis that the difference in lithic cultures between Neanderthals and modern humans comes from the difference in learning schedules.

Figure 1. An illustration of a learning schedule. Three discrete generations are shown. The duration of infant/ juvenile/adult periods determines the accumulation rate of culture, the equilibrium level of culture, and personal biological fitness.
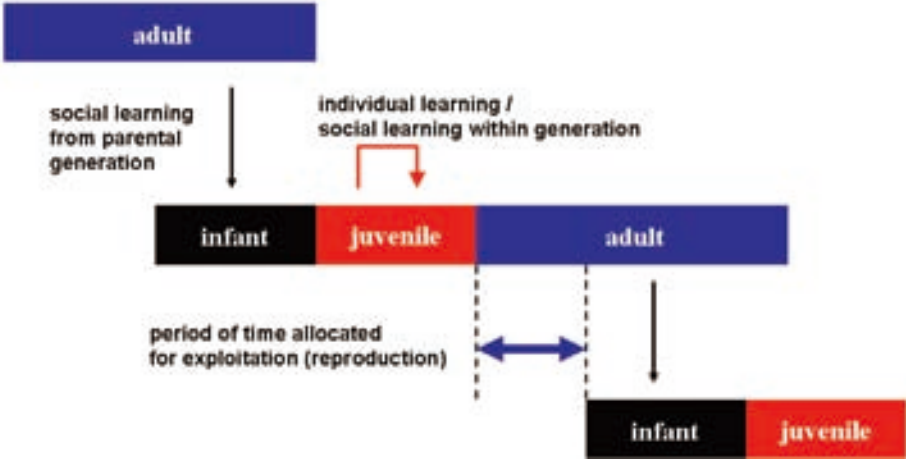
The Handaxe and the Microscope: Experience-Based and Fictitious Learning in a Geometric Model of Adaptation

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When individuals learn by trial-and-error, they perform and experience randomly chosen actions and reinforce those actions providing high payoffs. Cognitively more sophisticated individuals may evaluate the consequences of actions through mental simulation without experiencing them physically.

Such fictitious learners can select actions with high payoffs without making long chains of trial-and-error learning. Here, we analyze the evolution of an n-dimensional cultural trait (or artifact) under experience-based and fictitious learning in a payoff landscape with a single optimum. We derive the stochastic learning dynamics of the distance to the optimum in trait space when choice between alternative artifacts follows the standard logit choice rule. We show that for experience-based and fictitious learners, the learning dynamics stabilizes away at approximate distance $[n/(2L)]^{(1/2)}$ from the optimum, where L is an effective learning performance parameter depending on the learning rule under scrutiny. Learners, whether simple or sophisticated, are thus unlikely to reach the optimum when traits are complex (n large) and thus face a barrier to improvement. We show that this barrier can be significantly reduced in a large population of learners performing payoff-biased social learning, in which case L becomes proportional to population size. Overall, our results illustrate the effects of errors in learning, levels of cognition, and population size in the evolution of complex cultural traits.

Social Learning, Trial-and-Error, and Creativity

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Homo sapiens is a species whose behaviors are determined heavily by learning. It has been speculated that *Homo sapiens* have acquired such a high level of learning ability because it has been adaptive during the evolutionary history. Research on learning that employ mathematical modeling have assumed implicitly a dichotomy between individual learning and social learning, and examined under what conditions each type of learning ability can be adaptive. The key difference between these two is whether the source of information originates in oneself or others. Usually individual learning is considered a more basic ability since species who have very limited cognitive abilities, such as *Paramecium caudatum*, can have it, whereas social learning is a more advanced ability since it requires sophisticated cognitive and mental abilities.

One of the key insights in previous research is that cost and benefit of individual and social learning abilities are different. For an individual to learn by himself, he has to invest his resources. However, other individuals can imitate the fruit of his labor at no extra cost to themselves. This presents us with a free-rider problem. For each individual, it is better to engage in social learning. However, if everyone engages in social learning, new knowledge would not be acquired. Therefore, many previous studies assumed that there is a tradeoff between individual learning and social learning, and examined under what conditions social learning can be adaptive (e.g., Borenstein et al. 2008; Kameda & Nakanishi 2002; Wakano et al. 2004)

These previous studies have two problems, however. First, there is little empirical data on the relationship between individual learning and social learning among humans. Second, they assume that social learning is usually represented by the single ability of imitation, while individual learning is represented by either trial-and-error or creativity, although these two abilities are quite different from each other. Therefore, in the current study, we investigated the relationships between these three major human learning abilities for the first time.

We have conducted two experiments. Both experiments were conducted in the Group Experiment Lab at CERSS, Hokkaido University. Participants were asked to perform tasks designed to measure trial-and-error, creativity, imitation, and certain other abilities. They also answered a questionnaire which asked various questions regarding learning strategies.

Fifty-eight undergraduate students participated in the first experiment. The first experiment consisted of three types of tasks. The first one measured trial-and-error. We used the Lonpos game in which participants were asked to fill in empty spaces on a board with different-shaped pieces. The second task measured creativity. For that we used the two-string problem (Maier, 1945) and the candle holder problem (Dunker, 1945) both of which are known to measure functional fixedness in cognitive psychology. The third task measured imitation. For that we used a wire puzzle to see if participants become capable of solving the puzzle after watching a video of a demonstrator solving the

puzzle. The results suggested that the relationship between creativity and trial-and-error was negative, although they are usually both considered aspects of individual learning. The results also suggested that there was no trade-off between individual learning and social learning since no ability was negatively related to imitation. Finally, only creativity was positively related to imitation, which partly supports a new theoretical argument that a combination of social learning and individual learning is most adaptive under certain fluctuating environments (e.g., Aoki, 2010).

However, what we found in the first experiment is far from conclusive evidence since it was obtained from only a few specific tasks. Therefore, we conducted the second experiment to see if we can conceptually replicate the result of the first experiment. Sixty undergraduate students participated in the second experiment. In it, we used a new task to measure trial-and-error. We developed a coin game in which three buttons: a circle, triangle and a star, were displayed on the participant's computer screens. If participants clicked the buttons in a certain way, they would be rewarded with coins on the computer. Their objective was to figure out what pattern of clicking the buttons would get the coins. This is conceptually equivalent to the Skinner box, except that the reward is not real food. For creativity, we used several new tasks in addition to the candle holder problem. First, we used Cattell CFIT scale 3 form A, which is a test developed to measure fluid intelligence. Second, we used the ring task (McCaffrey, 2012). Third, we used two paper-and-pencil tasks; the truck task and the light task (McCaffrey, 2012). For imitation, we used the same wire puzzle. The results suggested that, contrary to the result of the first experiment, the relationship between creativity and trial-and-error was positive. There was no correlation between trial-and-error and imitation, same as in the first experiment. Finally, creativity was positively related to imitation, as was also the case in the first experiment. In conclusion, the results of the second experiment replicated most of the ones from the first experiment, except for the relationship between

creativity and trial-and-error. The candle holder problem was used in both experiments, yet it was negatively related to the Lonpos task and positively related to the coin game. The next step is to examine the validity of these two tasks.

Experimental Studies of Modern Human Social and Individual Learning in an Archaeological Context: People Behave Adaptively, but within Limits

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The aim of this conference is to explore the hypothesis that a key factor in the replacement of Neanderthals by modern humans was the superior learning abilities of the latter. To properly evaluate this hypothesis, empirical data are needed on the learning abilities of modern humans. This paper reviews a set of experimental studies conducted by myself and collaborators that have probed the learning abilities of contemporary humans when faced with a novel and complex task designed to resemble technology found in the material record. Hopefully, the findings of these experiments can inform both theoretical models of Neanderthal replacement and interpretation of the often ambiguous archaeological record.

The Virtual Arrowhead Task was originally designed by myself and archaeologist Michael O'Brien to capture the key aspects of North American projectile points [1,2], although we have since used it to explore the learning of complex technology in general [3-5]. Participants in small groups of 5-6 each design an arrowhead via a computer program (Figure 1). This virtual arrowhead is composed of three continuous traits (Height, Width, Thickness), which can each take any value from 1-100 arbitrary units, and two discrete traits (Shape and Colour), which can each take one of four categorical values. Over a series of trials (or 'hunts'), participants can improve their arrowhead by either individual trial-and-error learning, by directly altering the traits, or social learning, by copying the design of another group member. The form of this social learning (e.g. payoff bias, conformity) can be manipulated. On each hunt the participant tests their arrowhead in a virtual hunting environment, receiving a score in calories: the closer their design is to one or more hidden optimal designs pre-specified by us using fitness functions, the higher the score. Of particular interest is when there are multiple locally optimal designs, giving a realistic multimodal
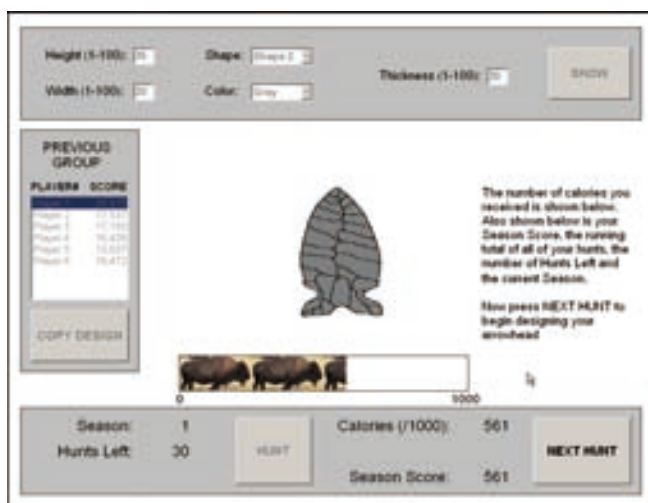
Figure 1. A screenshot of the Virtual Arrowhead Task. Participants can choose to directly change the traits in the box at the top (individual learning) or copy the design of another participant in the box on the left. Feedback is given in calories depending on how close the design is to one or more hidden optimal designs

adaptive landscape, implemented by giving the continuous traits bimodal fitness functions. Color is typically neutral and does not contribute to fitness in any way, and there is always a small random error in the score, simulating stochastic conditions such as weather or prey availability.

This task is intended to capture the key aspects of most complex technology, including that used by both modern humans and Neanderthals around the time of their coexistence: a technology composed of multiple constituent traits (some continuous and some discrete, some functional and some neutral), that is functionally opaque (no obvious, intuitive relation between an artifact and its effectiveness) and which has multiple locally optimal alternative designs (i.e. a multimodal adaptive landscape). In a series of studies we have explored how contemporary humans engage with this task, with the following key findings:

1. People are effective individual learners, but can get stuck on local optima

When playing alone, participants engage in a simple but effective reinforcement learning strategy [1,2]: modify a trait (e.g. increase Width), if the payoff increases then keep modifying the trait in that way (e.g. increase Width further); if the payoff decreases then do the opposite (e.g. decrease Width). This is done for each trait in turn until payoffs no longer change. The magnitude of the change negatively correlates with the participant's current payoff, i.e. low payoffs provoke bigger changes. This is adaptive: it allows big jumps across the adaptive landscape from low-fitness valleys to potentially high-fitness peaks. The downside of individual learning is that, in multimodal adaptive landscapes, participants get stuck on locally optimal but globally sub-optimal peaks.

2. People use payoff-biased social learning to jump to higher-fitness designs

When social learning is allowed, either after a period of individual learning [1] or concurrently with individual learning [4], participants readily engage in payoff-biased social learning, copying the design of the most successful person in their group. This is adaptive, as it allows them to outperform pure individual learners by jumping from low-fitness local optima to a higher-fitness peak that has been found by a better-performing participant. This use of social learning is flexible and dependent on the participants' own performance: only when performing poorly do participants engage in payoff biased social learning.

3. Social learning is used more when individual learning is costly

When individual learning is made more costly, by deducting calories every time a trait is directly modified, participants respond adaptively by engaging in social learning more frequently [1].

4. Payoff biased social learning is preferred to other forms of social learning

Payoff bias is preferred to conformity (copying the most common design), averaging (copying the average values of each trait in the group) and random copying (copying a randomly-selected group member) [5]. This is adaptive, as only payoff-bias allows participants to locate high-fitness peaks.

5. Payoff biased social learning leads to "cultural hitchhiking"

As noted above, Color was neutral and had no effect on payoff. Yet Color was copied just as faithfully as the functional traits during payoff-biased social learning [1]. This is an example of a neutral trait hitchhiking on functional traits; while this trait was neutral, it is possible that maladaptive traits also hitchhike in this way.

6. Informational access costs block social learning

In the above, participants could freely view other participants' designs. In one study, we let participants set 'informational access costs', which potential copiers had to pay them in order to view their arrowhead designs [4]. This blocked virtually all social learning, as the most successful participants set unreasonably high access costs that no other participant was willing to pay.

7. Separating individual learners from participants inhibits social learning

In one study, a separate pool of individual learners was used, rather than allowing participants to copy fellow group members [5]. As before, payoff-biased social learning was objectively the best strategy to

use, yet only a minority of participants engaged in it, possibly due to the reduced salience of the models.

8. Looking times are just as effective copying cues as objective performance

Participants preferentially copy other participants whom they have been told have been viewed longer by other group members [3]. This looking time information, a potential marker of prestige, was used just as often as objective success, suggesting that prestige may be a common shortcut for identifying who to copy.

Conclusions:

Contemporary humans behave largely adaptively when faced with a relatively complex and novel technology-design task, using feedback on their performance to flexibly switch between individual learning and payoff-biased social learning, and eschewing non-adaptive social learning strategies such as conformity and random copying. However, there are limits to this adaptiveness: information is not shared freely, at least in competitive tasks like this; neutral traits are unnecessarily copied alongside functional traits; separate pools of individual learners are not exploited well; and looking time information is used to identify from whom to copy as often as more reliable measures of objective success.

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Digital Reconstruction of the Neanderthal Amud 1 Cranium

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Fossil crania are often fractured and fragmented due to compaction and diagenesis. To restore the antemortem appearance of a fossil cranium, it is therefore necessary to correctly assemble the fragments. Conventionally, such reconstructions are created manually based on the knowledge and experience of skilled anthropologists. However, to investigate the difference in learning ability between Neanderthals and early modern humans in terms of anatomical differences in their brain morphology, it is essential to develop new computerized methods to realize more objective restorations of fossil crania. In this study, we developed a computerized technique for assembling fossil cranial fragments based on shape information, i.e., the smoothness of the joints between fragments and applied this technique for reconstruction of the Neanderthal cranium Amud 1.

We virtually removed glue and plaster from the original specimen and separated off the fragments constituting the fossil cranium. We then approximated the surface of each of cranial fragments using Bezier surface to extrapolate the surface and mathematically predict shape of adjacent fragments. The positions and orientations of adjacent fragments were calculated one by one by minimizing the fitting error. We assembled right and left sides of the cranium separately based on the above mentioned technique, and then put the right and left parts together mathematically based on smoothness of the joint, bilateral symmetry and the distance between the mandibular fossae determined from the associated undeformed mandible. As a result, smooth yet globally consistent assembly of the fragments of Amud 1 cranium became possible (Figure 1). The position of the isolated maxilla was determined by its complete mandible articulated to the mandibular fossae.

A reference modern human cranium was then warped onto the new reconstruction by iterative thin-plate spline deformation to restore complete exso- and endocranial morphology. Here we utilized the Gibraltar 1 to estimate position of landmarks on the missing basicranial and damaged endocranial regions.

The comparisons of the present computerized reconstruction with the original reconstruction indicated that the newly reconstructed Amud 1 cranium is slightly shorter, wider and lower in the anteroposterior, mediolateral, and superoinferior directions, respectively. Such computerized method allows detailed documentations of how the cranium was reconstructed, making restoration process reproducible and verifiable, while eliminating some of the subjectivity that may occur in restoration.

To estimate brain morphology of Amud 1 based on the reconstructed fossil cranium, it is necessary to quantitatively establish morphological correspondence between cranial endocast and brain surface morphology based on living human subjects using medical imaging technique. For this, the CT and MRI images from the same subjects were acquired and registered to each other such as to maximize mutual information between the two images. Endocast and brain surfaces were then

three-dimensionally reconstructed, and landmark coordinates were acquired to evaluate morphological correspondence between them. Our preliminary analysis demonstrated that such morphological correspondence between cranial endocast and brain surface does actually exist, suggesting that this correspondence relationship might be exploited for estimation of brain morphology of fossil human crania. We plan to derive spatial deformation functions from modern human crania to the reconstructed fossil cranium using thin-plate spline function, and use them to deform human brains to estimate brain morphology of the fossil cranium.
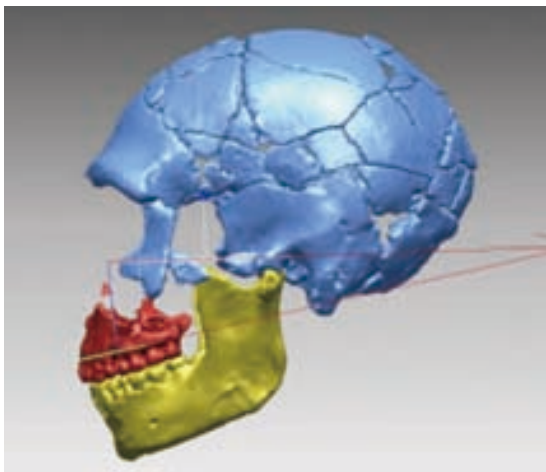
Figure 1. New assembly of the fragments of Amud 1 cranium.

Functional Craniology, Human Evolution, and Anatomical Constraints in the Neanderthal Braincase

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The relationships between face, cranial base, and neurocranium, have received much attention in the last decade, mostly taking into account changes associated with hominid evolution (Bookstein et al., 2003; Bastir et al., 2006). In particular, recent advances in digital anatomy and computed morphometrics have allowed to go beyond the analysis of individual traits variation, supporting quantitative approaches to study the integration between brain and braincase (Moss and Young, 1960; Richtsmeier et al., 2006). Neanderthals display some derived endocranial features, namely a relative widening of the prefrontal (Bruner and Holloway, 2010) and upper parietal areas (Bruner et al., 2003). Nonetheless, the braincase in Neanderthals retains more plesiomorphic characters than the modern human neurocranium, despite the similar cranial capacity in these two taxa (Gunz et al., 2010). The general allometric pattern associated with brain size increase in the human genus involves a longitudinal constraint of the midsagittal parietal surface, probably because of the contiguity with the frontal and occipital volumes and because of allometric relationships between cortical volumes and the falx cerebri (Bruner, 2004; Bruner et al., 2011a). In terms of bones, there is a marked integration between parietal and occipital structure (Gunz and Harvati, 2007). Interestingly, Neanderthals display hypostatic traits at the parieto-occipital junction, suggesting ossification problems associated with morphogenesis and balance between growth and development (Sergi, 1934; Manzi, 2003; Manzi et al., 1996). Neanderthals also lacked a complex meningeal vascular network, opening to speculations on possible thermal limits based on blood flow of the cortical surface (Bruner et al., 2011b). Taking into account all this information, we must consider the hypothesis that Neanderthals may have experienced structural problems in their braincase, reaching physical limits because of the plesiomophic neurocranial structure associated with a highly derived brain size. It is necessary to investigate whether or not such constraints may have influenced the evolution of the Neanderthals, their extinction, and their replacement by modern humans. In this sense also the relationships between structural organization and cognitive functions must be carefully considered, evaluating hypotheses to identify primary causes and secondary consequences.

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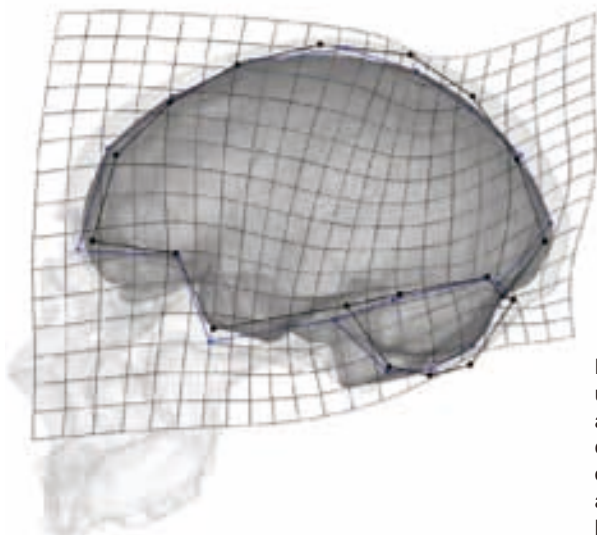
Figure 1. Neanderthals display a relative shortening of the upper parietal profile, as possible allometric consequence associated with encephalization and structural neurocranial constraints. The presence of hypostotic traits at the parieto-occipital boundaries may suggest morphogenetic problems associated with a derived brain size and a plesiomorphic braincase organization.

Virtual Endocast of Qafzeh 9, A Representative of Early Modern Humans

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Paleoneurology is an important field in the study of human evolution as it contributes important information to other areas of paleoanthropology. Variations in the size and shape of endocasts help in differentiating among fossil species. Moreover, comparisons of the size and shape of the fossil endocasts provide considerable links of the hard evidence to behavioral and cognitive differences among fossil species, which might have drove the speciation between the taxa. In this context, C01 team of the project RNMH (Replacement of Neanderthals by Modern Humans) aims to present reasonable ways for reconstruction of the fossil hominids in order to estimate the endocasts and the brains, and also aims to make possible inferences for behavioral and cognitive differences between Neanderthals and modern humans, based on the estimated endocasts and brains.

In this paper, we make an endocast from the fossil cranium of Qafzeh 9 and compare the size and shape of it with those of modern humans and several fossil hominids. At the same time, with assessment of the degree of deformation of the original fossil cranium, we try to correct the observed degree of deformation or distortion. Qafzeh 9 specimen is a fossil representative of early modern *Homo sapiens* and a key specimen in studies of expansion of *Homo sapiens* and of extinction of *Homo neanderthalensis*. However, the endocast of Qafzeh 9 was never produced.

Qafzeh 9 was discovered and excavated by B. Vandermeersch in 1969 from the Qafzeh Cave in Israel. It was associated with Middle Paleolithic assemblages of the Levalloiso-Mousterian culture (Vandermeersch, 1981). In spite of the older chronological age over 90,000 years and the older type of associated lithic assemblage (Tabun C type in Middle Paleolithic), the human skeletal morphology from the Qafzeh Cave is quite modern and contrasted to those of contemporary or even younger classic Neanderthals. According to his first description, the Qafzeh 9 individual is an adult female, whose cranial bones were crashed and heavily fragmented, but the whole cranium was well restored and reconstructed (Vandermeersch, 1981). The endocranial feature was only described on the parietal meningeal vessels because no endocasts have been made for this specimen. The degree of distortion was unknown, though the present reconstruction exhibits possible distortions both in the neurocranium and the face (Figure 1). By contrast, the endocranial capacity was calculated to be from 1508 to 1554 cc using several regression equations of the linear measurements (Vandermeersch, 1981), and the mean value of 1531 cc was reproduced in a textbook (Holloway et al., 2004).

We conducted a virtual reconstruction of the endocast from the CT-scan images of the specimen, with their planar resolution of 0.41 mm/pixel and the slice thickness of 0.5 mm. The process followed that of Kubo and Kono (2011), i.e. after extracting the cranial model from the CT images by using a threshold between the bone and air and making a physical mold of the endocranium with 3D printer, we filled the gap and repaired the lacking portions

of the inner cranial surface with clay (Figure 2). The more complete surface model of the endocast was produced from re-scanning images of the repaired mold. A preliminary estimation of the endocranial volume (ECV) was obtained to be 1411 cc. We should proceed to comparison of the ECV and the endocast morphology with those of comparative samples as well as assessment of the distortion and its correction.

In the preliminary study on the Qafzeh 9 cranium, we observed the significant distortion, which was determined as the degree of right-left asymmetry; the posterior neurocranium skews with the right-anterior and the left-posterior warping, and the face deviates toward the right as a whole. The correction value for the present Qafzeh 9 cranium can be given in terms of normal RL asymmetry observed in anatomical collections of modern human skulls, which will provide a meaningful deviation of the present Qafzeh 9 endocast, and may change the implication and understanding of its endocranial morphology.

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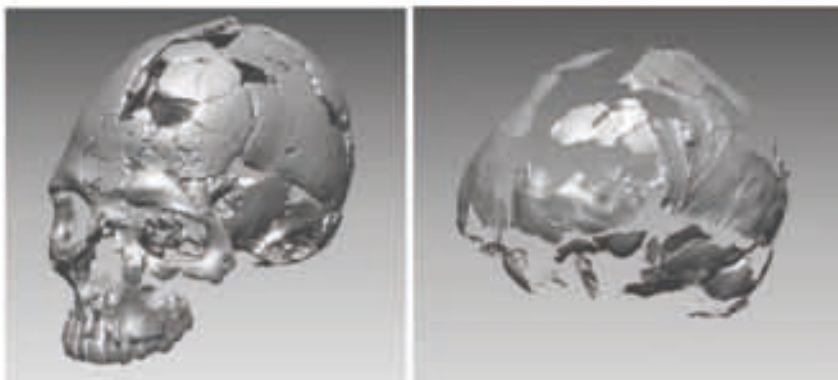Vandermeersch B (1981) Les Hommes Fossiles de Qafzeh (Israel). Editions du CNRS, Paris.

Figure 1. Qafzeh 9 cranium and endocast model.

Figure 2. Physical mold of Qafzeh 9 endocranium with infilled clay.

Cerebral Sulci and Gyri Observed on Macaque Endocasts

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Information on the cortical subdivisions of Neanderthal brains is essential in understanding the cognitive capabilities of this extinct hominid. To address this problem, we investigated characteristics of skulls that reliably indicate the borders of cortical areas. In the present study, we evaluated the correlation between the impressions on the inner surface of the skull and the cerebral gyri and sulci.

We used 5 aged monkeys (*Macaca fascicularis*, 3 males and 2 females) that had long been used for studies on the gastrointestinal tract and were scheduled to be euthanized. Under deep anesthesia with ketamine, xylazine and sodium pentobarbital, the animals were perfused transcardially with 2.5% formalin in phosphate buffer (pH 7.4) for 2 min (200 mL/min), followed by 10% formalin in the same buffer solution for 50 min (200 mL/min for initial 10 min, followed by 100 mL/min for the remaining 40 min). The first 2 cervical vertebrae were laminectomized, and the spinal cords were cut at C2-C3 junction, and the heads were separated from the neck approximately at the same level and stored in phosphate-buffered 2.5% formalin solution at room temperature. The heads were then scanned using Toshiba Asterion CT scanner at the Laboratory of Evolutionary Biomechanics, Department of Mechanical Engineering, Keio University to obtain 0.5 mm scan slices of 512 x 512 pixels.

The skulls and brains were next analyzed macroscopically and histologically at the National Defense Medical College. After removing the scalp, fascia, and temporalis muscles, we mounted the heads on a stereotaxic frame, and photographically recorded the surface of the calvaria. We then removed the calvaria and the dura mater, and recorded the surface of the brains. CT images were analyzed using Amira 5.4 (Visage Imaging, Berlin, Germany) on a Z620 workstation (Hewlett-Packard Japan, Tokyo, Japan).

Virtual endocasts that were created using CT data showed marked pattern of cerebral convolution (Figure 1). We observed impressions corresponding to most of the major cerebral sulci: the central, lateral, arcuate, principal, intraparietal, lunate, superior temporal, and anterior middle temporal sulci on the dorsolateral surface, as well as the medial and lateral orbital sulci on the ventral surface. The correspondence of the impressions to the cerebral sulci was confirmed by comparing the virtual endocasts with the brains of the same animal.

We further analyzed the individual differences in sulcal patterns of endocasts with those of the brain, and observed that some of the differences can be inferred by the endocasts, particularly in the frontal lobe: the medial and lateral orbital sulci (Figure 2), the arcuate and the principal sulci.

Usually, adult skulls of both Neanderthals and modern humans show hardly any impressions corresponding to the cerebral sulci except for the orbitosphenoidal crest and digital impressions of the orbital plate of the frontal bone. On the
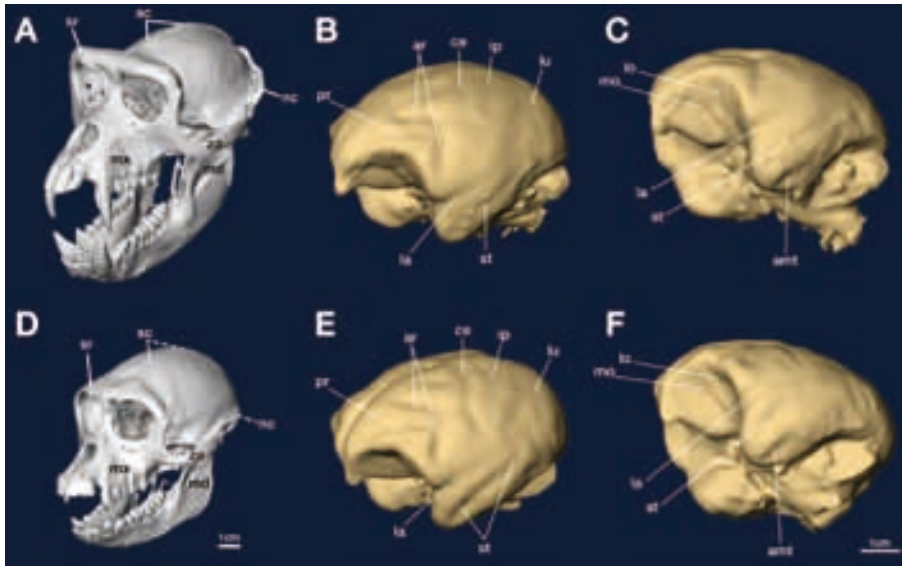
Figure 1. Reconstructed surface images of the skulls (A, D) and the virtual endocasts (B, C, E, F) of a male (M15, panels A-C;) and a female (M19, D-F) monkeys. Marked impressions corresponding to major cerebral sulci were identified: ar arcuate sulcus, pr principal sulcus, ce central sulcus, ip intraparietal sulcus, lunate sulcus, la lateral sulcus, st superior temporal sulcus, amt anterior middle temporal sulcus, lo/mo lateral and medial orbital sulci.
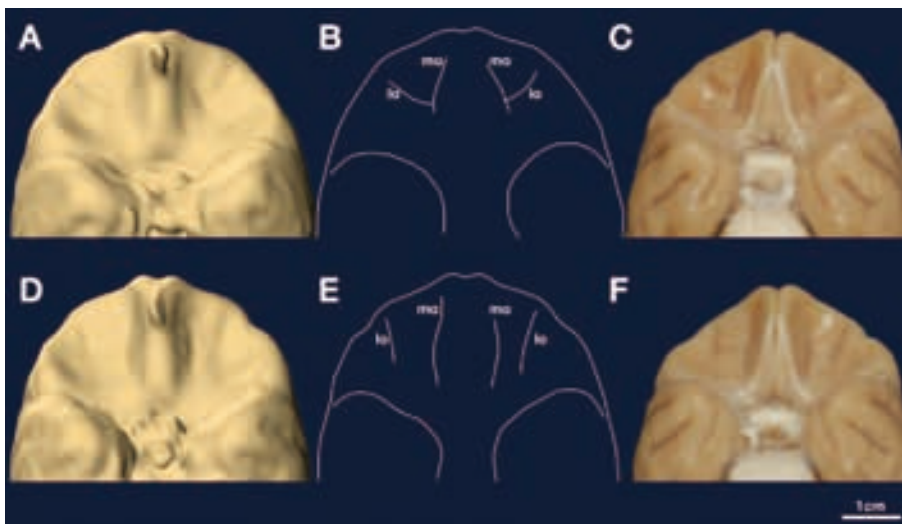
Figure 2. The orbitofrontal surface of two female monkeys (M17, panels A-C, and M19, D-F). Panels B and E illustrate the orbital sulci that were traced on the images of virtual endocasts (A, D). The lateral orbital sulcus of M17 joins the medial orbital sulcus on both sides (C), whereas the lateral and medial orbital sulci of M19 run nearly parallel to each other (F). These individual differences were well preserved on the endocasts.

other hand, impressions possibly corresponding to cerebral sulci were reported in some extant hominids such as Australopithecus. Infant skulls of Neanderthals exhibit some hints of convolutional pattern on their endocasts. These findings indicate that we may be able to identify cerebral sulci in small skulls that have relatively thin connective tissues intervening the skull and the brain.

Reconstruction of the Brain from Skull Fossil Using Computational Anatomy

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We investigated the presumed differences in learning abilities between Neanderthals and modern humans by combining evidence from the morphological analysis of fossil brains and the functional mapping of modern humans' brain functions. Our study faced a fundamental challenge: although we could easily collect various data about the structures and functions of the modern human brain, the only available data for the Neanderthal's brain were skull CT images reconstructed from fossilized brains produced by Project C01. Hence, to achieve our purpose, we had to establish a method for extrapolating to human brain functions from skull anatomy, which is the only data available for both modern humans and Neanderthals. In this study, we tried to develop a skull-based image registration method using the computational anatomy technique, a standard method such as functional MRI (fMRI) and voxel based morphometry (VBM) used in neuroimaging research. The basic idea is as follows: First, the skull shape reconstructed from CT images of a fossil brain is spatially deformed to the modern human skull shape segmented from MRI/CT image. Nonlinear spatial transformation method is used to estimate a globally one-to-one smooth and continuous mapping between these skull shapes. Diffeomorphic Anatomical Registration Through Exponentiated Lie algebra or DARTEL registration method is a promising candidate for our research. Using the deformation field estimated by the nonlinear transformation, the modern human cerebral cortex segmented from MRI image is then inverse-transformed to construct virtual Neanderthal's cortex which is consequently best fitted to its skull shape. This deformation is also applied to the functional brain map of modern human to presume the Neanderthal's one. The schema of this study is shown in Figure 1.

To validate our proposed strategy, we currently conduct a simulation analysis using modern human MRI. In this report, we compared the accuracy of the skull-based brain exchange between two modern human individuals with the brain (gray matter; GM and white matter; WM) -based exchanging. The procedures are as follows: Fifteen healthy subjects participated in this study. All MRI images were acquired using a 3-Tesla MR scanner (Siemens Allegra) at the National Institute for Physiological Sciences. A T1-weighted fine structural whole-brain image was acquired using a magnetization prepared rapid acquisition gradient echo (MP-RAGE). The parameters were as follows: TR=2500 ms; TE=4.38 ms; inversion time = 1100ms; FA = 8°; FoV = 230 mm; number of slices per slab = 192; voxel dimensions = $0.9 \times 0.9 \times 1.0$ mm. Image processing was performed using the Statistical Parametric Mapping package (SPM8; Wellcome Department of Cognitive Neurology, London, UK) implemented in MATLAB (Mathworks Inc., Sherborn, MA, USA). First, we segmented individual MRI images into GM (gray matter), WM (white matter) and Skull by segmentation-normalization algorithm in SPM. Then, using DARTEL registration method, the subj2-to-subj1 transformation was estimated with matching of their skull images or brain (GM and WM) images. Finally, inverse transformation

from subj1 to subj2 was applied to subj1's brain to construct the deformed subj1's brain in the shape of subj2's brain.

Figure 2 shows the result of the brain-based (upper column) and skull-based (lower column) exchange. The left and right row indicates the original MRI image for subject 1 and 2, respectively. The middle row shows the transformed subj.1 image, with the shape of subj2's brain. In the case of the brain-based matching, not only global features but also the local sulcus and gyrus arrangements were well-matched between the transformed (upper middle) and the original subj2's image (upper right). In the case of the skull-based matching, the global skull shape and the cortical surface shape were similar between the transformed image and the original image. However, there was obvious misalignment in the local structures as well as deep structures (e.g. size and shape of ventricle). To access the average accuracy of the transformation, we repeatedly applied this analysis to the pair of subject 2 and one of the remaining 14 subjects and then averaged the virtual subj2's brain images. We found that the global shape of the brain was well converged on that of subj2's brain even after skull-based matching, however, in terms of local accuracy, the only prominent landmark structures such as the lateral and central sulci could be identified on the averaged brain.

Following the results of this simulation and taking into account the application of this method to CT-image of a fossil brain, we will further investigate
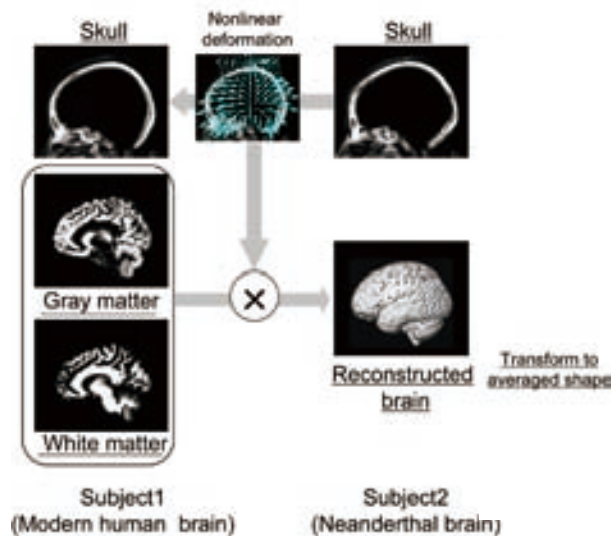
Figure 1. The schema of this study.

the following issues: (1) we quantitatively evaluate the similarity and difference in local features of the cortical surface between individuals. Deformation based morphometry analysis can be suitable for this purpose. This information might help to compensate for the lower resolution of the skull-based transformation. (2) we expand this method to handle the spatial registration between MRI and CT. Our goal is to establish the method for casting a modern human's cerebral cortex (MRI) from MRI in a Neanderthal's skull (CT) with matching between the modern human's skull (MRI or CT) and the Neanderthal's skull (CT). Hence, we should update our method to allow the multimodal image processing. We validate the accuracy of the method and clarify the problems in application to fossil brain CT.

Figure 2. Result of the brain exchange.

Innovative Society and Social Brains

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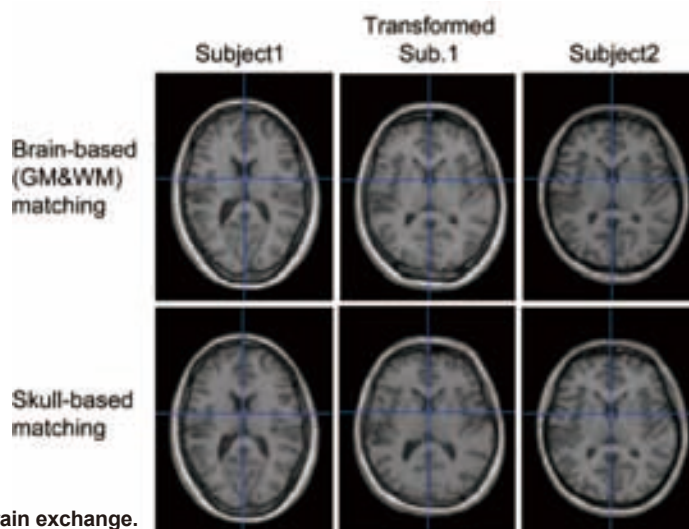Research team C02 adopts cognitive neuroscientific and comparative neuroanatomical approaches to examine our hypothesis that the replacement of Neanderthals by *Homo sapiens* was promoted by the differences in their learning abilities ('learning hypothesis'). By assuming that morphological changes in fossil skulls reflect functional differences between modern human brains and Neanderthal's brains, we try to identify gaps in learning abilities based on differences in cerebral morphology and region-specific activities using our developed analysis scheme (i.e. integrated system of computational neuroanatomy and brain function mapping).

From early 1990's, advances in magnetic resonance imaging (MRI) techniques have facilitated functional brain imaging and direct measurement of living human brain activities (i.e. functional MRI). Such techniques have enabled us to map the specific functions of the modern human brain. One of our team's goal is to create the maps regarding the difference of 'learning abilities' between Neanderthals and *Homo sapiens*. According to Tomasello (1999), some individual or group of individuals first invented a primitive version of the artifact or practice (i.e. creative or innovative activity; what we call individual learning ability), and then some later user or users made a modification or adopted without change for many generations (i.e. learned and used by others over time; what we call social learning ability) in *Homo sapiens* history. The important point is that the *Homo sapiens* is able to pool their cognitive resources, and the base of this ability is that they

can understand conspecifics as beings *like themselves* who have intentional and mental lives like their own (Tomasello et al., 1993). In line with this argue, we assume that innovative society is deeply correlated with the two components of the cognitive ability: 'intrinsic drive (internal motivation and perspective) to produce creative activity' and 'social cognition and interaction'.

In the present talk, I focus on the neural substrates of 'social brains'. Social brain is a circumscribed set of brain regions that are dedicated to the social cognition and interaction (Brothers, 1990). The most important attribute of the social brain is to make predictions about other's actions on the basis of their *mental states*, and this ability is developed from early stage of human life. As an example of these social cognitive abilities, I introduce our neuroimaging studies those investigate neural substrates of 'eye contact' and 'joint attention' (Saito et al., 2010; Tanabe et al., 2012). Both of them are the merkmals of the social cognitive abilities during the early development of humans. Eye contact affords to establish a communicative link between humans, and prompts joint attention. Joint attention is an ability to coordinate attention between interactive two persons regarding objects or events. The impaired development of it is a cardinal feature of autism spectrum disorder (ASD). As the eye contact is implicated in the sharing of various psychological states, it might provide a communicative context in which joint attention can be initiated. To elucidate the neural mechanisms of inter-subjective sharing during eye contact and joint

attention, we conducted a hyper-scanning functional MRI experiment while they were engaged in joint attention tasks with eye contact as the baseline. We assume that the eye contact based psychologically-shared mental states is neurally represented by the inter-subject synchronization of the 'state' of the brain activity, which is obtained by the elimination of the task-related activation component. In contrast, we detected brain regions related to joint attention in terms of task-related activity. Moreover, in order to compare the difference of neural mechanisms during eye contact and joint attention between typically-developed young adult individuals and those with high-functioning ASD, we try to elucidate brain regions those play important role in social cognition during eye-based communication. Our findings suggest that the right inferior frontal gyrus (IFG) plays an important role for shared intention during eye contact that provides the context for joint attention. Taken with other neuroimaging studies, we think that the right IFG is one of specific regions regarding the social cognition, and is a candidate for the difference between *Homo sapiens* and Neanderthals.

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Social Neuroscience of Stone Tool-Making Skill Acquisition

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Although there is a burgeoning neuroscience of tool use, there is little that might be properly called a neuroscience of technology. Anthropological and archaeological approaches to technology can help to provide a broader theoretical and evolutionary context. "Technology" is a fuzzy category that loosely corresponds to human actions that 1) involve the use or modification of objects, 2) display a complexly organized multi-level structure, and 3) are socially reproduced. These characteristics may be better understood with reference to neuroscience research on perceptual-motor control, object manipulation, motor resonance, imitation learning and goal-directed action. Research using neuroscience methods (PET, fMRI) to examine the archaeologically visible behavior of stone tool-making has provided insights into the past role of technology in human cognitive and brain evolution, including relations with the human faculty for language. A key focus of this research is to investigate mechanisms for the observational understanding and social reproduction of stone tool-making skills.

Study Implication Related to Sense of Acceptance: Key Factor of Social Learning

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Introduction

Cognitive and behavioral capabilities of modern humans, such as creativity, likely played a key role in the demise of Neanderthals. Both individual and social learning contribute to this creativity. For instance, in regards to individual learning, humans acquire new skills through trial and error processes; thus, this learning ability facilitates the invention of new skills and technologies. In social learning, on the other hand, humans acquire new skills by observing (Bandura, 1965) and imitating (Field & Walden, 1982) the behaviors of others. Social learning ability thus promotes the spread of the new skills and technologies invented by individual learning. Predominance of these two abilities of modern humans in comparison with Neanderthals might lead to replacement of Neanderthals by modern humans.

Modern humans have enhanced social abilities compared with other animal species (Dunber, 1998); indeed, the capacity for social learning is one of the major characteristics of modern humans. There are four necessary conditions of social learning processes: paying attention to a target, the retention and reproduction of a target's behavior, and motivation for imitation (Bandura, 1977). Acceptance towards others' behaviors contributes to the attention to the retention and reproduction the behavior. In addition, acceptance from others, i.e., approval, enhances the motivation to imitate the behaviors (Bandura, 1977). Thus, sensing acceptance from others might facilitate social learning processes.

Recent advances of neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), have revealed the neural correlates underlying a wide range of social abilities including a sense of acceptance. In this paper, we will review research related to the sense of acceptance, including the modulation of brain activation. Finally, we will introduce our future experimental plan.

Sense of acceptance

Sociometer theory has proposed that social acceptance from other people enhances self-esteem (Leary et al., 1995), and self-esteem is a consequence of the degree to which people receive acceptance from other people. As proposed in person-centered therapy, a sense of acceptance can influence on social behaviors through psychological contact (Rogers, 1957). Congruence, unconditional positive regard, and an empathic attitude of the therapist are the most important factors in person-centered therapy. Within successful therapy, client changed his / her way of thinking. This change of way of thinking promotes new social behaviors. Thus, perceiving a sense of acceptance contributes promoting new social behaviors through changing a way of thinking.

Functional MRI studies have shown that acceptance (praise) from others activates the striatum, which is part of the reward system (Izuma et al., 2008). On the other hand, rejection from others shows activation in the dorsal anterior cingulate cortex (ACC), part of the pain matrix

(Eisenberger et al., 2003), and is accompanied by a self-esteem decrease (Eisenberger et al., 2011a). Interestingly, social support has been shown to decrease psychological pain-related activation in the ACC during social exclusion (Onoda et al., 2009). Thus, social acceptance from others modulates brain activation in two ways: enhancement for reward-related activation and attenuation for pain-related activation.

Humans can also perceive a sense of acceptance even without the explicit words of others (Rogers, 1957), which likely stems from their nonverbal attitude. Perceived social support can come in the form of interpersonal touch (Coan et al., 2006). For instance, hand-holding with a spouse or stranger decreases the neural response to pain threat in the right anterior insula, superior frontal gyrus, and hypothalamus, including the affective pain matrix (Coan et al., 2006). In addition, a photo of romantic partner also decreases pain-related responses (Eisenberger et al., 2011b). Therefore, a sense of acceptance stemming from the nonverbal and verbal behaviors of others can modulate emotional related responses during social behaviors.

**Suggested experiment on the sense of acceptance**
Remained issue:

Despite the progress in research on the sense of acceptance, there are still issues that need to be resolved. First, as mentioned in the introduction, a sense of acceptance enhances social behavior. However, the neural correlates underlying the link between a sense of acceptance and the enhancement of social behavior is unresolved. Second, the motives for social behavior mainly consist of psychological factors. Thus, the link between negative feelings stemming from psychological factors and a sense of acceptance warrants further investigation.

Example of experimental design outline:

In this article, we suggest a potential experimental design regarding the link between negative feelings stemming from psychological factors and a sense of acceptance. In this type of experiment, empathic pain, the negative feeling aroused by seeing others in pain (Singer et al., 2004), can be treated as psychological pain. Other conditions in the experiment include supportive words or hand holding as a sense of acceptance. For this experiment, each subject observes painful or non-painful visual stimuli throughout the session. They then evaluate the stimuli while the left hand of a familiar person is placed on their hand (human hand condition). Alternatively, the control condition is when a non-human (e.g., rubber) hand or no hand (non-hand condition) is used.
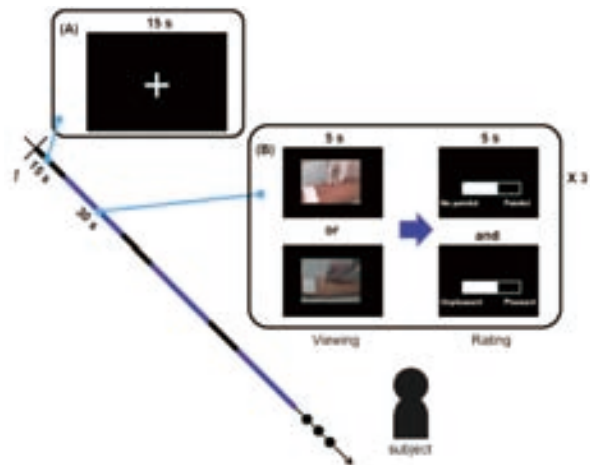
Figure 1. Time chart example of visual stimuli presentation.

Conclusion

In this paper, we have indicated the importance of a sense of acceptance for promoting social learning. The sense of acceptance has been investigated in wide range of studies including its underlying neural mechanisms in regards to social behavior or psychological factor effects. However, there is a missing link at the mechanistic level among social behavior, psychological factors, and sense of acceptance. Our proposed experiment may help clarify the neural mechanisms underlying social learning.

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Neural Substrates of Motivation to Learn and Fatigue

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Differences in learning abilities are thought to be demonstrated by elucidating the brain regions involved in individual and social learning of modern humans using neuropsychological methods, and by comparing the differences of brain regions between modern and ancient humans based on fossil reconstruction of ancient human brains. The study project for Replacement of Neanderthals by Modern Humans (RNMH) has focused on the neural bases of learning control (enforced learning) in individual learning and of imitative learning in social learning.

Although motivation to learn is an enforced factor for individual and social learning, the neural substrates associated with motivation to learn have not previously been determined. Therefore, we investigated the neural substrates of motivation to learn in modern humans using functional magnetic resonance imaging (fMRI). We confirmed that sense of accomplishment was an intrinsic reward is associated with motivation to learn (Yoshida et al, 2008). In addition, the striatum was strongly activated by sense of accomplishment, and striatal activation levels were positively associated with a motivation-to-learn score derived from a questionnaire (Mizuno et al., 2008). As academic rewards for motivational arousal, there are senses of accomplishment and competence, self-efficacy, and acceptance by others (Deci et al., 1991, 1996). Neural bases of acceptance by others have been also reported using fMRI. Perception of a good reputation by others induces activations of the medial prefrontal cortex and striatum (Izuma et al., 2008). These results suggest that striatum plays crucial role for motivation to learn.

In children and adolescents, there is a negative correlation between motivation to learn and fatigue, which is likely to be two sides of the same coin. This finding indicates that fatigue is a negative reinforce to motivation to learn. Our collaborators revealed that the medial orbitofrontal cortex was associated with fatigue sensation using positron emission tomography (Tajima et al., 2010). Recently, we also confirmed that activity of the medial orbitofrontal cortex was increased depending on time on fatigue-inducing task using fMRI. In addition, the activation of medial orbitofrontal cortex was attenuated by the perception of intrinsic reward, suggesting that intrinsic reward modulates fatigue alleviation level.

In addition to clarify the neural bases associated with motivation to learn and fatigue, we tried to determine what cognitive function is correlated with level of motivation to learn and/or fatigue. The neural substrates of that cognitive function may provide evidence for discussion of the differences in learning abilities between modern and ancient humans based on the differences in the brain morphologies and functions between them. In children and adolescents, we explored the association between motivation to learn and other cognitive functions, and found that motivation to learn was positively correlated with performance on a divided attention task (Mizuno et al., 2011a). We used *kana* pick-out test (Kaneko, 1996), which is one of the verbal dual task, to evaluate the ability

to divide attention. In contrast to the motivation to learn, fatigue was negatively correlates with the performance of divided attention task (Mizuno et al., 2011b). In addition, we found that ability to divide attention was dramatically developed from childhood to adolescence (Mizuno et al., 2011c). Taken together, these results suggest that motivation to learn and fatigue influence the age-dependent development of cognitive function in children and adolescents.

The fMRI study revealed that processing of divided attention acquires activation of the left dorsal inferior frontal gyrus and superior parietal lobule in young adults (Mizuno et al., 2012). In children and adolescents, we also found that these brain regions were activated during the same divided attention task, and the activation levels are affected by the extent of motivation to the task and baseline fatigue. These results suggest that increased activations of these frontal and parietal regions during dual task performance may be associated with the capacity for attentional resources. In modern humans, it is known that these cortices develop from childhood to adulthood.

These findings highlighted the regions of interest of the brain, such as striatum and orbitofrontal, frontal and parietal cortices, in relation to motivation to learn, fatigue and cognitive function affected by motivation and fatigue in modern humans. Morphological and functional comparisons of these regions between modern and ancient humans are expected to help elucidate differences in learning abilities between modern and ancient humans. We expect these outcomes to contribute the achievement of the RNMH project.

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Poster Presentations

Poster

Aimed Spear-Throwing in Modern Humans: A Preliminary Study of Upper Limb Kinematics

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Introduction

Humans have the ability to throw with speed and accuracy. A few non-human primates, such as tufted capuchins (Westergaard *et al.*, 1994), Japanese macaques (Leca *et al.*, 2008), and chimpanzees (Osvath, 2009), reportedly also have the ability to throw. Although Isaac (1987) stated that throwing behavior in the context of human evolution had drawn little scholarly attention, this situation is changing. Recently, biomechanical methods have been used to identify anatomical factors that affect the throwing performance of modern humans and to evaluate the throwing ability of earlier *Homo* species (Roach *et al.*, 2012).

The existence of anatomical features that enhance throwing performance does not necessarily mean that the species used throwing-based projectile weapons in hunting. The spear thrower (atlatl or woomera), which is unequivocal evidence of hunting with a projectile weapon, came into use after the disappearance of Homo species other than modern humans (see Schmitt *et al.*, 2003 and references therein). The oldest known spears were discovered in Schöningen, Germany, and dated to 400,000 years ago, the time of *Homo heidelbergensis* or the early Neanderthals in Europe (Thieme, 1997; for evolutionary scenarios for the origin of the Neanderthals, see Rightmire, 2008 and Hublin, 2009). Whether these spears were throwing- (Thieme, 1997; Rieder, 2003) or thrusting-based weapons (Schmitt *et al.*, 2003) is controversial.

I am currently undertaking a research project to better understand throwing behavior, particularly spear throwing, in Neanderthals and modern humans. In this presentation, I report the results of two experiments: electromyography (EMG) of the biceps brachii during forearm supination, and upper-limb kinematics in spear throwing with a spear thrower.

Experiment 1: EMG of the biceps brachii during forearm supination

There are a number of features in which the morphology of the Neanderthal postcranial skeleton differs from that of modern humans (Trinkaus, 1983; Aiello and Dean, 2002; Weaver, 2009). Some of these features are unique to the Neanderthals (autapomorphic), whereas others are shared with earlier hominins (symplesiomorphic) (Weaver, 2009).

In the Neanderthals, the radius had a more medially positioned radial tuberosity than that found in modern humans (Trinkaus and Churchill, 1988; De Groote, 2011). A medially positioned radial tuberosity is also observed in the apes, particularly in the orangutans and chimpanzees (Aiello and Dean, 2002). The radial tuberosity provides the insertion for the biceps brachii muscle, which serves as a supinator of the forearm as well as a flexor of the elbow. However, an EMG study carried out by Travill and Basmajian (1961) showed that this muscle generally remains inactive during slow supination and during supination with the elbow extended. The medially positioned radial tuberosity in the Neanderthals may have maintained the moment arm of the biceps brachii for supination throughout forearm rotation, suggesting that the Neanderthals had more power in pronation with the elbow flexed than do modern humans (Trinkaus and Churchill, 1988).
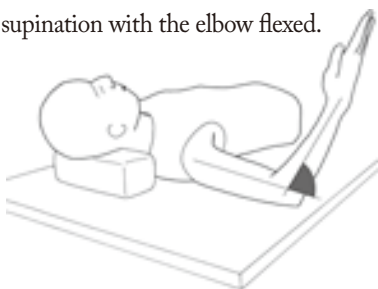
Here, I studied the activity patterns of the biceps brachii during forearm supination in more detail. Many parts of this experimental protocol were adapted from Travill and Basmajian (1961). The EMG activity was
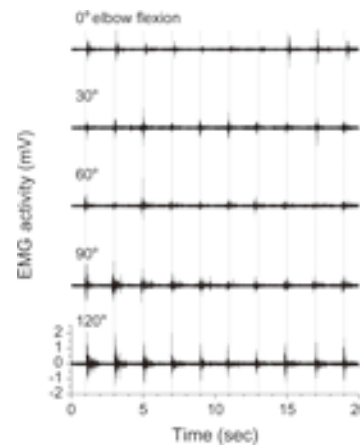
recorded at 1 kHz from the dominant biceps brachii using bipolar surface electrodes. Simultaneously with EMG measurements, video recordings were made at 60 Hz using a digital camcorder. While performing forearm rotation tasks, the participant lay supine on a padded table and abducted the dominant shoulder at 90° (Figure 1). Each task involved 20 repetitions of a series of movements that started with the forearm in a full supination, moved to full pronation, and then returned to the start position (supination). Forearm rotation tasks were carried out at two speeds (slow and fast) with the elbow flexed at five different angles (0°, 30°, 60°, 90°, and 120°). Under the slow-speed condition, the participant performed every forearm pronation or supination for 1 second. Under the fast-speed condition, the participant performed these movements as fast as possible at 1-second intervals.

Generally, the biceps brachii muscle was active during supination and remained inactive during pronation. During supination at the slow speed, the biceps brachii was active when the elbow was flexed at 60° to 120°, but the amplitude of the activity was very small. During supination at the fast speed, the biceps brachii was active with the elbow flexed at any angle (Figure 2). One-way ANOVA showed that the maximum EMG activity at the fast speed was significantly higher at 120° than at any other angle of elbow flexion (all values, $p < 0.05$). Although the difference did not reach statistical significance, the maximum activity was higher at 90° than at smaller angles of elbow flexion.

This experiment generated both similar and different results compared with those of Travill and Basmajian (1961). The difference might be due to the small number of participants in this experiment or the types of electrodes used. Nevertheless, the results support their finding that the biceps brachii shows marked activity during fast supination with the elbow flexed.

Figure 2. Raw EMG traces of the biceps brachii during fast forearm rotation in a participant. Pronation and supination were alternately performed as fast as possible at 1-second intervals. Gray vertical lines roughly correspond to the onset of supination.

Experiment 2: Upper-limb kinematics in spear throwing with a spear thrower

I studied body movements during spear throwing with a spear thrower to explore the following topics: mechanics of the spear thrower works, upper-limb kinematics, and anatomical differences between Neanderthals and modern humans that might affect their throwing ability. Participants were instructed to throw a spear-like object at a target using a spear thrower (Figures 3 and 4). Video recordings were made using digital camcorders. To aid in data analysis, spherical reflective markers were placed on bony landmarks of the body, and the movement of these markers was recorded using motion-analysis software and digitized.

Figure 3. A spear thrower from the top view (left) and the side view (right).

Figure 1. In Experiment 1, a participant performed a task while lying supine with the shoulder abducted at 90°. The elbow was flexed at 0° (no flexion), 30°, 60°, 90°, and 120°. The amount of elbow flexion is illustrated in gray.
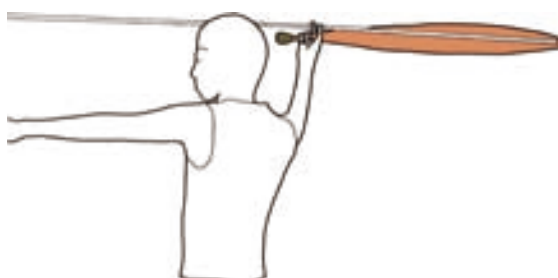
Figure 4. A spear thrower in use.

Neander DB 2.0: Improvement of the "Replacement of Neanderthals by Modern Humans" Lithic Industry Database

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This paper reports the recent progress of the "Replacement of Neanderthals by Modern Humans" lithic industry database (Neander DB) project of the research team A01 (archaeology). The aim of this project is to map and analyse the spatio-temporal processes of the replacement of Neanderthals by anatomically modern humans (AMHs) in higher resolution than in the previous researches. For this purpose, members of the database team are collecting the information on archaeological sites and lithic industries in Africa and Eurasia between 200 k.a. and 20 k.a.[1] As of September 30, 2012, Neander DB has recorded a total of 376 lithic industries from 3,832 cultural layers of 1,977 sites and 5,182 radiometric samples. These data was compiled from a total of 547 literature sources including excavation reports, research papers, and monographs. In addition to the European databases published [2], Neander DB is covering the whole part of Africa, Asia, and Near Oceania.

An increasing number of records have led us to realise inter-regional inconsistencies in the terminology of lithic industries, spatial unit, and periodisation. First, lithic industries sometimes have different local or regional terms. For example, Mousterian is known as the industry that belonged to Neanderthals and has dozens of variant names. Some of these indicate typological or technological variants (Denticulate Mousterian, Levallois-Mousterian, etc.), while others predicate regional (Altai Mousterian, Zagros Mousterian, etc.) or temporal vatiation (Late Mousterian,

Final Mousterian, etc.). Second, the concept of "cultural layers" has originally been developed in the Levant and Europe because there are a number of Palaeolithic cave or rock-shelter sites in which anthropogenic deposits are geologically layered. However, it is difficult to apply the same concept to open sites in Siberia and other regions. Third, different durations of period are referred in different regions and different fields of research. When attempting to fit the archaeological chronology in that of the palaeoenvironmental sciences, we should refer to MIS (marine isotope stage) as common time scale.

In order to fix these problems, the metadata structure of Neander DB was thoroughly reviewed and the numerical cardinalities between the tables of site (cultural layer), lithic industry, and period were reorganised. In the new version, Neander DB 2.0 (Figure 1), one cultural layer is related to one and more lithic industries, and each industry belongs to one and more regions, regionally defined time periods, and MIS. This alternation also allows us to describe multiple industries in open sites where the distinction of geological layers is unclear.

Neander DB 2.0 was launched in July 2012. With clarified metadata structure, it successfully provides more accurate text-based retrieval of the attributes such as periods, lithic industries, and presence of fossils (Figure 2). In my view, Neander DB 2.0 will act as a powerful analytical tool to visualise and understand the spatio-temporal pattern of the "replacement" of Neanderthals

by AMHs in several parts of Eurasia. By collaborations with informatics specialists of the project headquarters in near future, an online database and map architecture with associative retrieving system will be developed for the next generation database, Neander DB 3.0, which will be launched when we publish the dataset at the final phase of the project.

[1] Kondo, Y., S. Kadowaki, H. Kato, M. Naganuma, A. Ono, K. Sano, and Y. Nishiaki (2012) Network computing for archaeology: a case study from the "Replacement of Neanderthals by Modern Humans" lithic industry database project. In: M. Zhou *et al.* (eds.) *Revive the Past: Proceeding of the 39th Conference on Computer Applications and Quantitative Methods in Archaeology, Beijing, 12-16 April 2011.* Amsterdam: Amsterdam University Press, pp. 217-226. http://dare.uva.nl/aup/nl/record/412958

[2] D'Errico, F., W. E. Banks, M. Vanhaeren, V. Laroulandie, and M. Langlais (2011) PACEA geo-referenced radiocarbon database. *PaleoAnthropology* 2011: 1-12. doi: 10.4207/PA.2011.ART40.
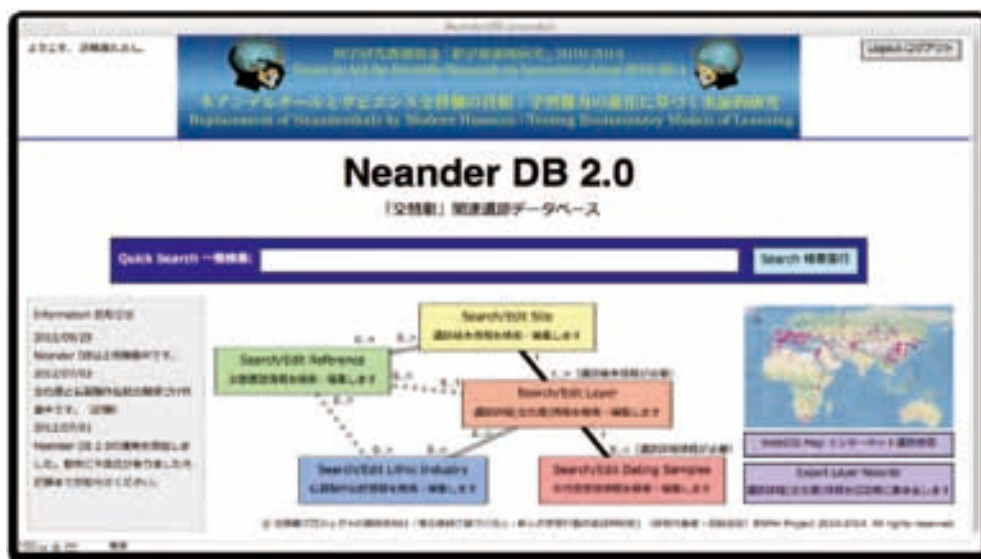
Figure 1. User interface of Neander DB 2.0 and schematic diagram of the entity relationship.

Figure 2. Location of the paleoanthropological sites recorded in Neander DB 2.0 (as of September 1, 2012).

The Initial and Early Upper Paleolithic of the Japanese Archipelago

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In Paleolithic studies of Japan, we eliminated all the "fake" materials and then re-started to clarify the Initial and Early Upper Paleolithic (hereafter, IUP and EUP respectively) or lithic industries earlier than the IUP and EUP. One of the current issues is how we correctly identify lithic artifacts in considering lithic industries preceding the Upper Paleolithic. To identify lithics, we have to observe individual pieces carefully, but the contexts in which lithics are found are also important.

The earliest lithic industry in Japan has been found in the Tachikawa loam layer X, dated to 35ka, in the Kanto district. In this industry, I identified three lithic technologies: heavy duty tool technology, flake technology and blade technology. Then, I sub-divided each of these technologies according to retouched tool types and further technological features.

Figures 1 and 2 show that the IUP of Japan encompassed a variety of lithic technologies, among which notable are assemblages with denticulates and ventrally retouched scrapers as well as those with a block core reduction technology. Denticulates are associated with ventrally retouched scrapers in Kyusyu. Because these assemblages do not include trapezoids, backed blades, or blade technology, they are likely to precede in date the Upper Paleolithic
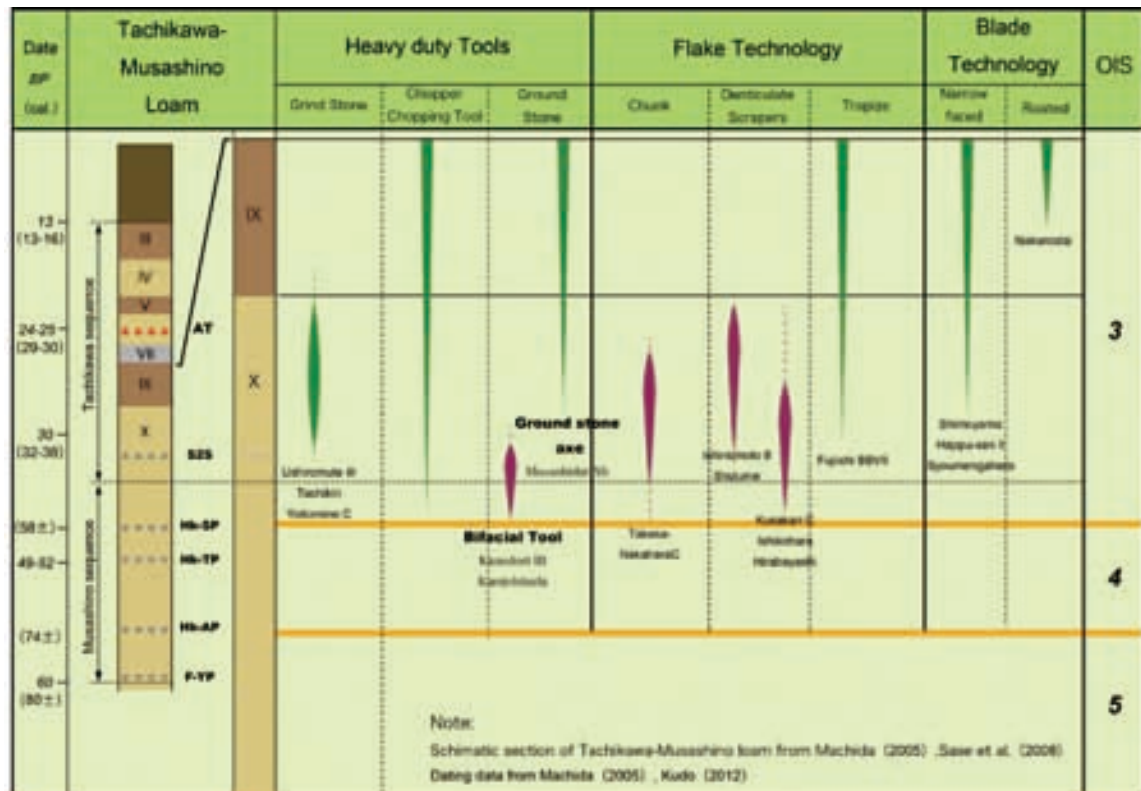

Figure 1. Major lithic technologies of the Japanese Upper Paleolithic.

in the Kanto district. The block core technology is similar to the "chert" flake industry found in the Tachikawa loam layer X in Kanto. These industries with denticulates/ventrally retouched scrapers or block core technology do not appear to have continued in the Kanto district during the EUP. They were replaced with assemblages with trapezoids, backed blades, produced by flake technology or blade technology, and edge-ground tools. On the other hand, the denticulate and scraper industry continued in Kyusyu.

Presently, it is difficult to determine whether these technological differences between Kanto and Kyusyu represent social traditions or adaptations that differed between the two regions. For now, we stress that there was a large variety of lithic industries in Japan during the IUP. This implies that the replacement of the old technology, characterized by denticulates and scrapers, with the following blade technology in the IUP occurred over a period of their co-existence. However, no biological evidence is currently available regarding the producers of these lithic industries.

I'm grateful to Dr. Seiji Kadowaki and Mr. Takehiro Miki for their assistance in preparing the English manuscript. I'm, however, responsible for the contents of the paper.
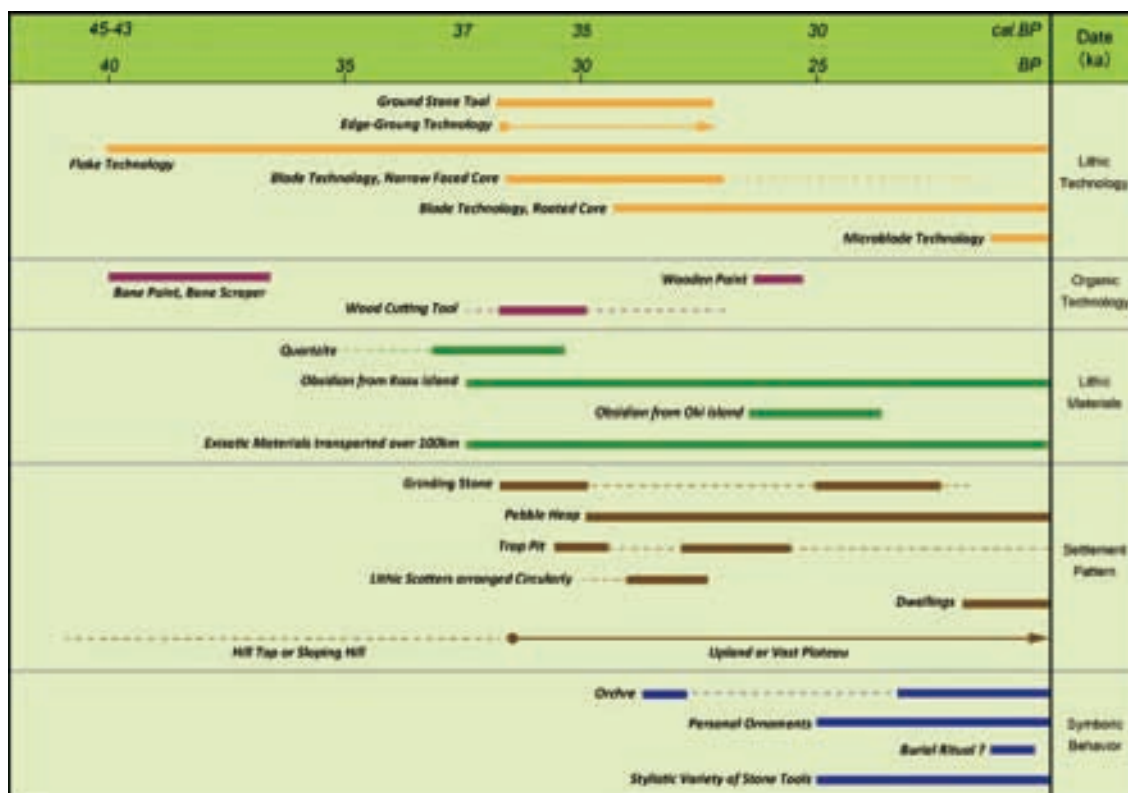

Figure 2. Chronological occurrences of selected technological and behavioral elements in the Japanese Upper Paleolithic.

The Archaeological Database for the RNMH Project

Yoshihiro Nishiaki

The University Museum, The University of Tokyo, Japan

A team of archaeologists working on the RNMH project has been constructing an extensive archaeological database (called NeanderDB) to determine temporal changes in the distribution of Neanderthal and early modern human sites on a global level. The database is intended to facilitate discussion on time-space contexts and the nature of the replacement process of the Neanderthals by early modern humans (Kondo *et al*., 2012; Nishiaki, 2012). The team consists of the following members and their collaborators:

Director: Yoshihiro Nishiaki (The University of Tokyo)

Programming: Yasuhisa Kondo (Tokyo Institute of Technology)

Africa and West Asia: Seiji Kadowaki (Nagoya University)

Europe: Katsuhiro Sano (Tohoku University) and Akira Ono (Meiji University)

Siberia and Central Asia: Hirofumi Kato and Masaki Naganuma (Hokkaido University)

South Asia: Kazuya Shimogama (Ancient Orient Museum)

Southeast Asia: Shinji Yamasaki (Okinawa Prefectural Museum) and Takehiro Miki (The University of Tokyo)

East Asia: Kenji Nagai (Tohoku College of Arts and Designs) and Hiroto Nakata (Aoyama-Gakuin University)

Comparable Paleolithic databases currently available include the *Stage Three Project* database (Van Andel and Davies, 2003), the *PACEA* database (D'Errico *et al*., 2010), and the *ROCEEH* database (Haidle *et al*., 2010). Each database is valuable in its own right. For example, the *Stage Three Project* database focuses on archaeological sites of Europe, and as indicated by its name, it concerns sites dating to MIS 3. The *PACEA* database also focuses on European sites but limits its coverage to those that can be dated by the radiocarbon method, that is, 50 ka and younger. The *ROCEEH* database is the most extensive, containing detailed information on archaeological sites in Africa and Eurasia beginning at two million years ago. Partly due to its very large geographical and chronological scale, this project is planned to continue for a considerable period.

Similar to the *ROCEEH* database, the RNMH *NeanderDB* covers much larger geographic areas than the *Stage Three Project* and *PACEA* databases. However, it limits the time range to between 200 and 20 ka in order to focus on the period beginning with the appearance of the first anatomically modern humans in Africa and ending with the demise of Neanderthals in Eurasia. Moreover, *NeanderDB* contains a detailed list of archaeological finds for each assemblage such as bone tools, ornaments, mobile art, and specific types of lithic tools (Kondo *et al*., 2012). Such a list allows users to examine the invention and maintenance of patterns of a particular cultural item across geographical regions so that we can then test the "learning hypothesis." Another unique aspect of the *NeanderDB* is that it incorporates a wealth of information from regions outside of Africa and Europe such as Siberia, South and

East Asia, and Oceania. Particularly rich are the data from East Asia, collected from literature in Chinese, Korean, and Japanese. Clarification of the time-space context regarding the emergence of the Upper Paleolithic in East Asia, whose indigenous populations were probably not Neanderthals, can be compared to the insights obtained from studying the Neanderthal record elsewhere.

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Lithic Refitted Materials and Identification of Technical Skill Level: Lessons from the Upper Paleolithic Assemblages of the Shirataki Sites in Hokkaido, Northern Japan

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My purpose in this paper is to reassess a significance of the lithic refitted materials in order to explore the learning and skill transmission process in the lithic production. I approach this issue through the analysis of the enormous lithic refitted materials obtained from the Upper Paleolithic assemblages at the Shirataki sites, Hokkaido, Northern Japan. Importantly the Shirataki sites are located nearby a huge outcrop of obsidian that is of good quality, with few interior inclusions. Therefore, the Upper Paleolithic inhabitants of the sites procured lithic raw materials from these local obsidian sources, and a large amount of lithic production was done at the respective sites. Analyzing and comparing of these lithic refitted materials encourage us to examine the relationship between the contexts of past knapping activities occurred at the site and how skill was expressed materially.

To address such issue, I attempt to assess not only the technological characteristics which have been generally understood as skill signatures in the previous approaches, but also presence of blade core as well as the degree of absence of blade among the refitted materials. The former concerns whether the blade cores expected to be included in the refitted materials are recovered from the site or not. The latter refers a comparison between the estimated number of produced blades and the estimated number of missing blades in the respective refitted materials. It is highly probable that the blade cores and the blades that good results were achieved technically were exported from the Shirataki sites, with an anticipation of

further use as blanks or tools. Conversely, the majority of the products knapped by the novice left on the spot where they were struck from, which confirms the hypothesis that a simple training exercise took place (Bodu et al., 1990). Whether the blade cores as well as the blades are present in particular assemblage may provide us with important information on the skill of knappers and the context of past knapping activities. Of course, when the accidental flaking seriously occurred, for example, resulting from the inferior inclusions or the joint surfaces in the obsidian gravels and debris, and the operational sequences were just terminated by the error, the blade cores should be abandoned at the site. In other cases, the criterion for abandonment is related to the economic threshold: work stops when the core only allows the manufacture of products of insufficient size (e.g., Karlin and Julien, 1994). Without knowing just how checkered preceding flaking may be, we should not automatically regard the presence of blade cores as indicator of the skill level concerning the prehistoric knappers.

In this paper, I present data documenting the skill learning processes based on the analysis of the Late Upper Paleolithic assemblages obtained from three sites in the Shirataki sites: the Hattoridai 2 site, the Kamishirataki 8 site, and the Kamishirataki 2 site.

First, I attempt to analyze the refitted materials obtained from the concentrations Sb-23~31 at the Hattoridai 2 site. A comparison of the refitted materials shows that a correspondence of the skill signatures with presence of the blade cores and the

blades is apparently recognized. Indeed, different skill levels of the knappers are associated with the selection of raw materials; the skilled knappers might use angular and sub-angular obsidian gravels as lithic raw materials. In contrast, the apprentice knappers might use grounded obsidian gravels for the blade reduction. Consequently, we can understand that the skill of prehistoric knappers in this concentration was combined with selection of the form of raw materials, regardless of a consideration concerning an influence from the technological needs and behavioral contexts.

It is noteworthy that the distribution of refitted materials made by the skilled knappers and the novice knappers is spatially separated in this assemblage. This is valuable patterning because such distributional pattern perhaps gives a clue to infer the social relationship between the multiple knappers with different level of skill. In spite of a few data to claim that the knapping activities in this assemblage were conducted simultaneously, a distinction of the spatial patterning enable us to interpret that the activity zones of the skilled knappers and the novice knappers are differentiated based on well-defined spatial rules, and such rules therefore might be recognized among both knappers. This patterning is nevertheless different from the case of the Paris Basin where reserving the best places around the hearth for the skilled knappers and keeping the apprentices outside the domestic space are seen (Pigeot, 1990).

Second, I focus on the lithic assemblage from the concentration Sb-90 at the Kamishirataki 8 site. Careful preparations as well as repeated rejuvenations on the striking platform and ridge are virtually recognized in all of the refitted materials. Although the morphological features of obsidian gravels vary among these refitted materials, the technological characteristics observed in the blade reduction process and its products are surprisingly similar. Also, there are a few differences in the technological evidences in relation to the skill signatures among these refitted materials. Consequently, it is hard to identify a difference in the technical skill level of the knappers, in spite of

that variability can be seen in the morphological features of the raw materials. The evidence presented here offers that the knappers involved in the formation of this assemblage had an equivalent skill to produce the blades. They used the various form of obsidian gravels as raw materials to remove the blades, which is a contrast to the case in the Hattoridai 2 site.

In these refitted materials, blade cores are present except for few specimens. Conversely, the vast majority of blades supposed to be detached among these refitted materials were largely exported from the site. Therefore there is an inconsistency between them. Interestingly, I can recognize that remarkable accidental flaking such as hinge fracture scars and other irregularities usually occurred in the preceding flaking before abandonment through the observation of these refitted materials, especially conjoining with the blade cores. Such accidental flaking might result in the abandonment of cores at the site. As a result, there are not the refitted materials viewed as reflections of different levels of technical skill from the concentration No.90 at the Kamishirataki 8 site. Furthermore, it is of interest to note that the skill signatures clearly correlate with not the absence of blade cores, but the absence of blades.

Third, I analyze the refitted materials from the concentration Sb-9 at the Kamishirataki 2 site. There are four refitted materials relevant to the blade reduction in this assemblage. Each of them, conjoining many of blades and flakes, clearly shows that how the raw materials were selected, how preparations and rejuvenations of blade cores were repeatedly employed, and subsequently how and what blades were removed. It appears that the blade productions in these refitted materials were progressed in much the same way. Large chunks of obsidian debris were commonly used as raw materials in these refitted materials. The diameters of raw materials selected in this assemblage are about 40 cm. Then, the regular and long blades, from almost 10 cm up to 30 cm in length, were subsequently aimed to detach among these blade reductions. To address it, the multistage reduction

sequences including the careful preparation and several rejuvenations stages of striking platform as well as ridge on these blade cores, were executed. These were always connected with rubbing the pecked platform, presumably with the aid of abrasives. When the accumulation of hinge fracture terminations on the face of the cores as well as the striking platforms occurred, the knappers often restored to rejuvenating the flaking surfaces and platforms to eliminate the accumulations of errors created on these cores. Therefore, the technological features, common to all of blade refitted materials in this assemblage, allow us an interpretation that the knapper had the high skill to maintain cores for producing the formal blades effectively and cope with the errors appropriately.

However, it is of interest to note that many of blades detached from the blade cores in this assemblage were abandoned at the concentration Sb-9, while some of the blade cores were exported from the site. In these cases, every stage in the course of manufacturing processes was performed with utmost precision, but almost all of the products were left on the spot. This is in contrast to the case of the Kamishirataki 8 site, as described above. These materials can be interpreted as "academic cores" (Johansen and Stapert, 2008): cores worked by an expert knapper in what seems to be a pedagogic demonstration for the benefit of a beginner knapper. One conclusion that can be drawn is that its purpose of the expert knappers was not to produce good blades for immediate use, but to instruct.

Comparison between Individual, Imitative and Instructive Learning

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One of the most important research questions on differences of learning abilities between the Neanderthals and the modern humans (MH) is to clarify differences between social learning and individual learning psychologically. It is evident that the Neanderthals transmitted their skills to make stone axes by means of social learning, especially imitation. The MH could make creative individual learning as well as imitation. Individual learning with creativity of the MH is obviously different from individual learning universally conducted by non-social animals. Additionally the MH can make instructive learning as a special style of learning specific to *Homo sapiens* (Strauss, 2005; Csibra and Gergely, 2006; Ando, 2009, 2012).

Although imitative learning is a kind of social learning in a sense that learning occurs in a social situation in which models to be imitated exist, it is also a kind of individual learning because it depends on subjective understanding of how to represent models' skills to be learned and how to regulate learners' own learning processes. On the other hand, instructive learning is evolutionarily idiosyncratic because there exist a person who costly and altruistically control other person's learning of learners.

In the current preliminary study, therefore, three different styles of learning - individual, imitative and instructive learning - were compared to clarify nature of learning in the MH; how efficient they are, how motivations to imitate/ to be imitated and to teach/ to be taught are regulated?

Methods

Participants:

20 university students (12 females, 8 males); mean age = 20.8 yrs (SD= .77)

Materials:

Three sets of disentangled puzzles; Puzzle I (Key), II (Horse), and III (Disk) (Figure 1) .

Procedures:

There were three phases; individual, imitative, and instructive learning.

(i) Individual learning (IndL); To solve the first puzzle alone without any assistance by other.

(ii) Imitative learning (ImitL); To solve the second puzzle in the situation that a learner is permitted to imitate a model (who learned the target puzzle in Phase (i)) solving the same puzzle.

Puzzle Ⅰ (Key)

Puzzle Ⅱ (Horse)
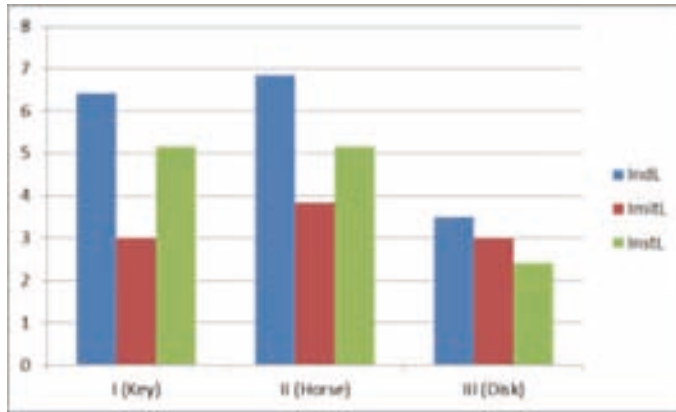
Puzzle Ⅲ (Disk)   **Figure 1. Materials.**

Figure 2. Learning efficiencies of each phase.

(iii) Instructive learning (InstL); To solve the third puzzle in the situation that an instructor (who learned the target puzzle in Phase (i)) is permitted to teach and a learner is permitted to ask an instructor to teach how to solve a puzzle.

Three participants built a team and each participant in a team solved a different puzzle in each phase. Trial was identified as success when participant could disentangle two pieces of puzzle and entangle them again. The number of successful trials within 10 minutes was an index of learning efficiency.

After the Phase (i), feelings of easiness, task involvement and challenge were asked. After the Phase (ii), feelings of attention to partner and competition as a model and learner (imitator) were asked. After Phase (iii), teaching motivation (as an instructor) and feeling of being taught directly and indirectly (as a learner) were asked.

Results

Frequencies of successes on each phase for three puzzle tasks is shown in Figure 2. Although no significant differences were found for these frequencies of each material, individual learning tended to be the most efficient among three learning conditions.

Person who feel easy on a task tended to pay more attention to imitators (r=.53) and person who feel more competitive feeling while imitating tended to feel more competitive while being imitated (r=.76) and less being directly taught (r=-.72).

Discussion

Imitative and instructive learning conditions looked more time consuming than individual learning to solve these tasks and, for competitive person, were not motivating to be taught. Task difficulty and motivation to teach/to taught might be interact with each other for efficiency.

Elements of Social Learning Among Hunter-Gatherer and Farmer Children in the Central African Republic

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Life history theory predicts that the pace and timing of developmental changes are evolved features of an organism's life cycle. Humans are reliant on social learning for survival and it has been argued that human childhood evolved, at least in part, because of the opportunity it provided for social learning for the ancestors of *Homo sapiens* in our environment of evolutionary adaptation roughly 200,000 years ago. Thus, it is hypothesized that the capacity for cumulative culture, which has allowed our success as a species, has coevolved with our lifespan. While much early social learning consists of cultural information–shared ideas, beliefs, values, knowledge, and skills held in the minds of other people–culture also patterns human behavior and in part determines who children learn from and in what settings learning takes place. It follows that, if childhood is an adaptation to learn skills necessary for survival and reproduction within an information-dense social environment (i.e. a culture) then children should:

1) seek out and attend to social information and should be the targets of teaching and social feedback;
2) spend less time on learning behaviors with age as skills and knowledge are internalized;
3) form social relationships with those who are going to be most useful to learn from–those who children identify with or are similar but more knowledgeable than themselves.

In this study, these predictions are tested using data from children in two small-scale societies: the Aka hunter-gatherers and Ngandu farmers of the Central African Republic. I examine social learning processes and the social contexts of learning.
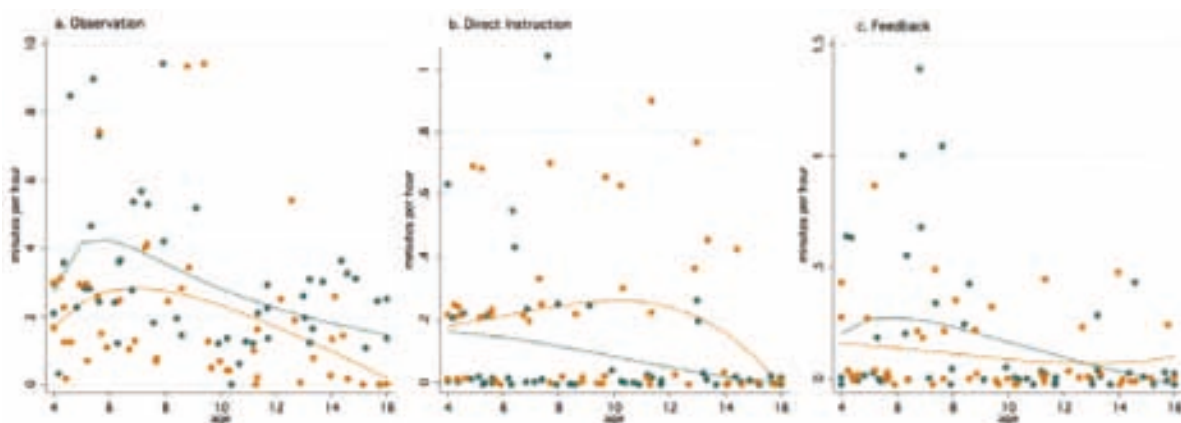

Figure 1. Fractional polynomial smoothing curves of hourly rates of social learning processes by age. Green indicates Aka, orange indicates Ngandu. Note the difference in scale of the y-axis on each graph. Jitter was added to the scatter plot with a noice factor of 5.
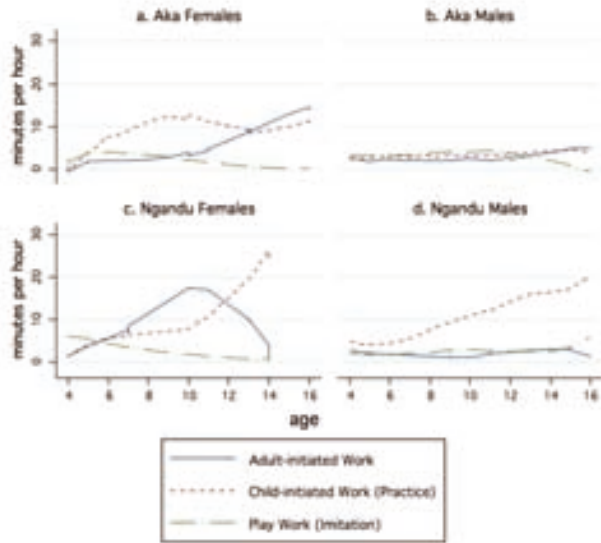
Figure 2. Lowess besi-fit lines of work and play rates during Aka and Ngandu childhood. In general, girls spend more time working than boys. However, it is clear that Ngandu children take the initiative during middle childhood, and work independently of adults. Aka, on the other hand, begin to work alongside adults at this time.
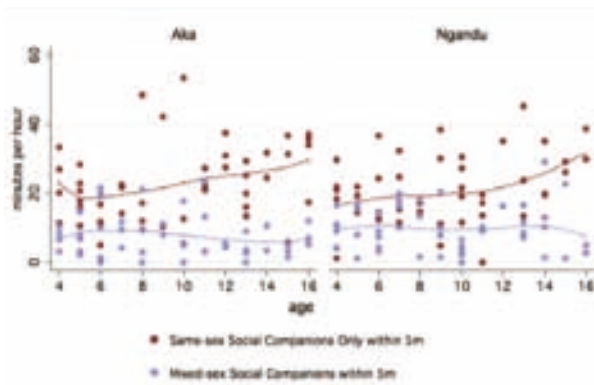
Figure 3. Rates of proximity to same-sex only versus mixed sex nearest neighbors (social companions). Lines are lowess best-fit lines.
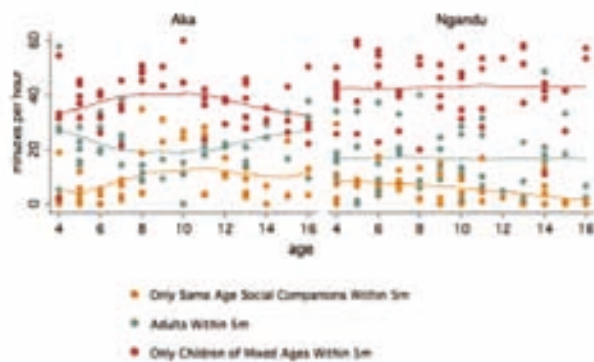
Figure 4. Rates of proximity to social companions of different classes across ages in both cultures. Orange indicates only children of the same age category (4-6, 7-12, or 13-16 years old) are within 5 meters of the focal child. Teal indicates at least one adult is within 5 meters of the focal child. Red indicates that at least one child older or younger than the focal child is within 5 meters.

Daily Physical Activity and Time-Space Allocation of Pygmy Hunter-Gatherers' Children in Southeast Cameroon

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Introduction

This study aimed to evaluate the physical activity and daily time-place use of hunter-gatherers children, and to examine the relationship of these indices in one of the most traditional populations in the world.

Materials and methods

A complete survey was conducted on 44 Baka children (28 boys and 16 girls, 2-16 years old) living in the same village (total 86 inhabitants) in East region of Cameroon during short dry season. All participants wore a small GPS unit for conclusive 3 days, and the GPS log data were collected (44 children, 131 person-days). From the log data, total travel distance (TD: km/day), activity radius (AR: m/day) and the daily trip times (hours/day) for each activity points (e.g. Own village, Forest and River...) were calculated. Elder 21 children (13 boys and 8 girls) wore an accelerometer pedometerwith GPS unit for the same periods, the acceleration and the steps data were gained, and the physical activity level (PAL) was calculated.

Results and discussion

The physical activities of participants were considered to be very high. The average of PAL and steps were above 2.0 and 20,000 for both sexes (Table 1). Furthermore, the daily PAL were classified into "vigorous" in 73% (46/63 person-days) of all observation, and 95.2% (60/63 person-days) of participants walked more than the international recommendations.

As the age increases, TD was generally increased and AR was expanded (for both indices, $r = 0.70$ and $P < 0.0001$), however, a small dispersions were found in elder boys for both indices. There was a strong positive correlations between steps and PAL ($r = 0.82$, $P < 0.0001$), and moreover, TD and AR significantly increased as the steps increased (TD: $r = 0.82$, $P < 0.0001$ and AR: $r = 0.64$, $P < 0.0001$). These results suggested that the physical activity of hunter-gatherer's children is related to walking.

There was a sex-age differenceamong daily time-place using (Table 2). In boys, time spent for "forest (1.07 vs. 3.03 hours/day; younger vs. elder)" and "other village (0.05 vs. 1.85 hours/day)" were prolonged, and the time stayed in "own village (21.6 vs. 16.9 hours/day" was markedly decreased. By contrast, there was no notable change for time-place using in girls.

There were significant positive correlation between the time spent for "forest" and four physical activity indices (TD, AR, steps and PAL). However, there were negative correlations between time spent in "village" and these four indices. It is considered that going out from the village might increase children's physical activities.

Table 1. Physical activities of participants.

		Boys				Girls			P
		N	Mean	±	SD	N	Mean	±	SD	
Steps		39	25,331	±	9,348	24	22,400	±	4,258	ns
PAL		39	2.08	±	0.21	24	2.10	±	0.15	ns
TD	(km/day)	83	10.0	±	5.1	48	8.6	±	4.0	ns
AR	(m/day)	83	480.1	±	347.9	48	496.9	±	440.6	ns

non-paired t-test, ns: no significant difference ($P \geq 0.05$)

Table 2. Daily time-place allocation (hours/day) by sex-age distribution.

Place	Boys		Girls		Sex	Age	Sex × Age
	Younger	Elder	Younger	Elder			
Village (own)	21.6	16.9	21.2	20.1	*	***	**
Forest	1.07	3.03	2.02	1.92		**	**
River	0.61	0.83	0.72	0.58			
Water	0.15	0.27	0.03	0.44		**	
Village (other)	0.05	1.85	0.00	0.41	**	***	**
Others	0.40	0.79	0.09	0.56		*	

Two-way ANOVA, *: $P<0.05$, **: $P<0.01$, ***: $P<0.001$
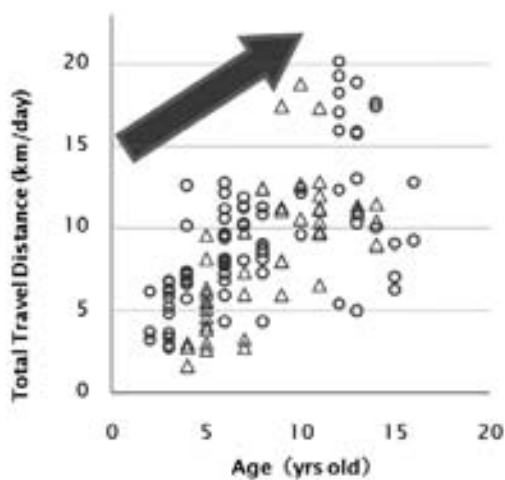

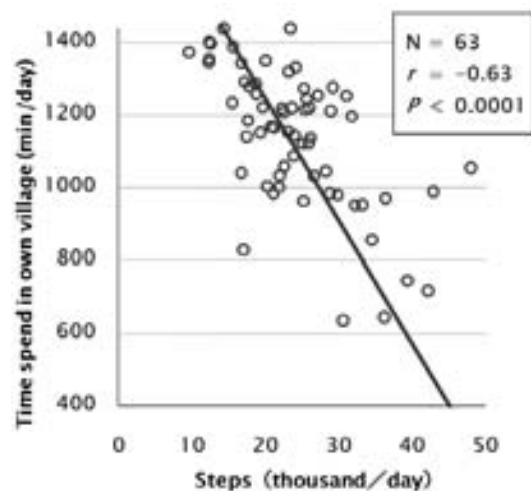**Figure 1. The increment of total travel distance (km/day) by age.**

Figure 2. The correlation between steps (steps/day) and time spend in own village (min/day).

Technical Transmission of Hunting Tool Manufacture: A Case of Spear Hunting Among Modern Hunter-Gatherers in Southeast Cameroon

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In this study, we present fundamental data associated with spear hunting among the Baka, who are modern hunter-gatherers in southeast Cameroon. Moreover, the spear as a hunting tool was used by Neanderthals. We decided to examine "learning hypothesis" through looking at functionality, cultural aspects and the manufacturing process. We focused on the distribution of manufacturing techniques among the Baka and among generations in addition to the measurement of spears that are in use. In particular, we noted the nature of educational discourse and activity relating to these spears and their deployment.

Between August 1 and 9 in 2012, we visited five settlements and one half-settlement of the Baka near Lomie in southeast Cameroon. We measured 34 spears and interviewed 34 persons. As a result, we were able to verify the diversity of spears (size, shape, quality of material, etc.; Table, Figures 1 and 2). No obvious relationship between the form of a spear and the game being hunted was found except in relation to large mammals such as elephant.

Although detailed information about the Baka's actual hunting activities was limited, we were able to obtain useful data relating to the age of interviewees and the manufacture of spears. Among the interviewees 18 answered that they had experience of manufacturing spears. Of these, six persons were producing spears in their "adolescent (wanjo: teens, premarital period)", four persons were in their 20s, five persons were in their 30s and one person was in his 60s (*four persons did not provide an answer). Eleven of 12 persons responded that they had made more than one spear. Six of 11 persons responded that they had made more than five spears. Of these, one person had made around ten spears, while the elder had made "countless".

Regarding the teaching of spear manufacture, 11 of 18 persons responded that they were taught by their father and 2 claimed that they were taught by their grandfather. It is noteworthy that all responders said they had "learnt by observing" the manufacturing process rather than from any "direct teaching". On the other hand, 8 of 14 persons without inexperience of spear manufacture answered that they obtained a spear by gift (donation) from their kinship group. Thus, it can be observed that kinship serves as a background to both the manufacture and donation of spears among the Baka. However, regarding actual spear manufacture, in spite of kinship relations, elders (experienced persons) do not directly conduct any teaching. It appears that spear manufacture is always an independent activity.

The first spears tend to be made during adolescence. At one time, it was considered by Baka men that there was a symbolic aspect to hunting with spears during premarital adolescence. On the other hand, when we pursued this with some Baka adolescents, none of them were experienced in spear manufacture and only one of them actually owned a spear. Therefore, we inferred that spears were mainly important as hunting tools. However, there has been a spread of hatchets, steel wires and guns as modern hunting tools. At the same time, in recent years the frequency of hunting expeditions have been reduced by deforestation and the establishment of a

national park near the Baka's immediate forest area. Consequently, a decline in the hunting activities which use a spear is likely to be matched by a decline in the technical tradition surrounding the manufacture of spears.

In this study, we also describe and analyse the results of some interviews with elders regarding the practice of spear manufacture (Figure 3).

Table: Spearhead types and their frequency at the study villages.

| Classification | Shape | | Barb | Size | Hafting method | Number |
	Plan	Section				
Type 1	leaf	ridged	absent	large	socket	6
Type 2	leaf	lozenge	absent	middle	socket	8
Type 3	leaf	rectangle	absent	middle	socket	7
Type 4	leaf	parallelogram	absent	middle	socket	2
Type 5	leaf	lozenge	absent	small	socket	2
Type 6	leaf	lozenge	absent	small	integrated	3
Type 7	leaf	lozenge	absent	small	tang	1
Type 8	arrowhead	lozenge	absent	small	tang	2
Type 9	leaf	ridged	one pair	middle	socket	1
Type 10	arrowhead	lozenge	many pairs	small	socket	2
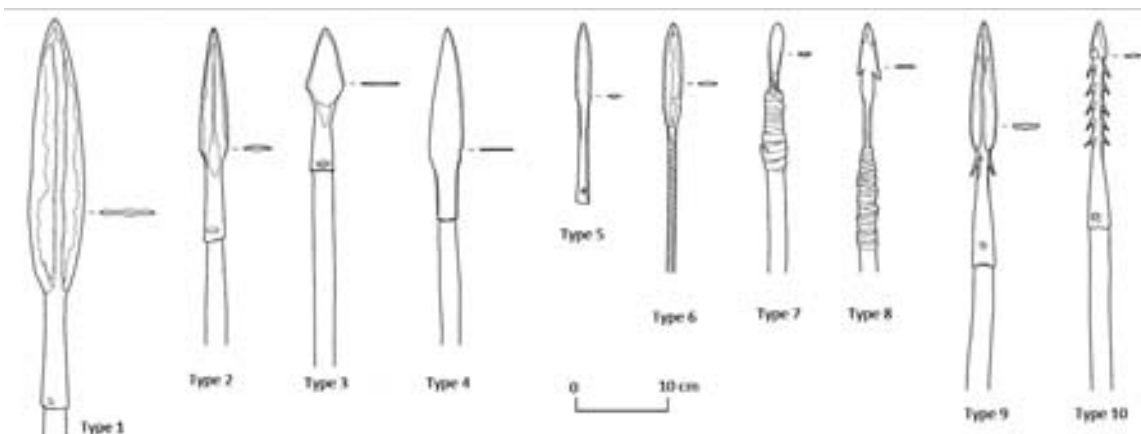
Figure 1. Classification of spearhead types among the Baka.

Figure 2. Type 2 spearhead.

Figure 3. Spear manufacturing among the Baka in Cameroon.

"Finding the Spirit to Create" Innovation and Social Learning Among Aka Adolescents of the Central African Rainforest

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Innovation and social learning are often described as responsible for playing significant roles in the evolution of cultural systems with arguments chiefly structured around the transmission and diffusion of novel information, behaviors and or artifacts, the receptivity of a society to inventions and the role of innovation as an adaptive response to highly variable climatic or social conditions, providing solutions to new problems and reducing uncertainty and risk (for definitions of innovation and invention see O'Brien and Shennan, 2010: vi-18; Henrich in O'Brien and Shennan 2010: 99; Kameda and Nakanishi, 2002; Barton *et al*., 2011). However, not all innovative behavior is in response to environmental adversity and instability, nor developed to meet specific needs (Henrich in O'Brien and Shennan 2010; Diamond, 1999: 246). Inventive behavior is not unique to humans, and as with social learning, often occurs in a variety of ways and ecologies (Nishida 1987; Galef, 1990; Tomasello *et al*., 1993, in Boesch, 1995; Boesch and Tomesello, 2003; Kameda and Nakanishi, 2002: Lalande and Reader in O'Brien and Shennan, 2010: 37-52). This study is framed around economic, organizational, and ideological factors influencing the creation, adoption and transmission of a new behavior, artifact or technology, including; societal organization; proximity to others; social value and prestige accrued to the innovator; "ownership rights," to the technology/behavior (i.e. protection of rewards for the inventor); indigenous understandings of the advantages of the new behavior or technology;

risk-taking and exploratory behaviors and; social valuation of individual creativity (Diamond, 1999: 246).

This research examines the nature, indigenous understandings, and transmission of innovation in a hunter-gatherer group. Since little is known about this topic in foragers, much of the research is primarily inductive and descriptive. Data were collected from in-depth interviews and systematic ranking and sorting techniques with 20 Aka adolescents of Central African Republic and 5 Aka adult individuals identified as being "innovators". Data included exploration of indigenous concepts and terms of innovation, characteristic features associated with innovations, and free listing of individuals identified as "innovators". Further research incorporated free listing of character qualities of the "innovators", in-depth interviews with adolescents seeking out new knowledge (e.g. innovative behaviors or inventions) and in-depth interviews with individuals identified as being innovators. The study tentatively predicted the following hypothesis based upon developmental and evolutionary theories:

1. Older adolescents will be more innovative than children and older adults because of developmental increases in cognitive capacity and the potential reproductive value of innovative behavior.

2. Older adolescent males will be more likely to seek out inventions as they are more likely to engage in risk-taking and exploratory behaviors and more likely to travel greater distances than

females (McDonald and Hewlett, 1999; Hewlett *et al.*, 1986; see also Reader and Laland, 2001).

3. Innovations would be spread by horizontal transmission, a characteristic form of transmission in adolescence (peer, intergenerational) (Hewlett *et al.*, 2002).

4. Older adolescents would pay attention to prestigious ("successful") peers from whom to learn (Henrich in O'Brien and Shennan, 2010: 99-120).

Contrary to expectations, incidences of innovative behaviors occurred more frequently in middle-aged adults than adolescents, with males more often being listed as innovators than females. Adolescents of both sexes were more likely to seek out, and pay for, new behaviors, inventions and technologies than were adults or children. Both male and female adolescents sought out new inventions from adults rather than peers, but male adolescents did not seek out innovations from female adults, while female adolescents sought out both adult males and females to learn from. Both males and females frequently listed being seen as more attractive to the opposite sex as the reason for acquiring new behaviors and or technologies.

More data from small-scale populations are necessary for formulating precise understandings of innovation, social learning and cultural transmission in contexts that characterized most of human history. The consequences of environmental and biological changes interacting with culturally driven behavioral changes, innovation, decision making and social learning may well have been necessary for the survival of the ancestors of modern humans, and help to explain the extinction (or "absorption") of Neanderthals during the Late Pleistocene (Barton *et al.*, 2011: 725; see also Henrich in O'Brien and Shennan 2010).

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Table 1. Composite salience for Aka attributions of innovative people; Males and Females Combined.

Attributes	Attributes ℓ	Composite Salience ℓ/n (n=23)
Kind	9.61	0.42
Quiet	9.08	0.39
Wise	6.47	0.28
Intelligent	6.42	0.28
Good	6.27	0.27
Happy	3.52	0.15
Advisor	2.47	0.11

Figure 1. Basket old vs 'new'.

Table 2. Composite salience for Aka attributions of innovative people; Males Only.

Attributes	Attributes ℓ	Composite Salience ℓ/n (n=13)
Kind	6.53	0.50
Good	5.77	0.44
Quiet	5.41	0.42
Wise	2.8	0.22
Happy	2.69	0.21
Intelligent	2.67	0.21
Advisor	1.47	0.11

Figure 2. Women's basket.

Table 3. Composite salience for Aka attributions of innovative people; Females Only.

Attributes	Attributes ℓ	Composite Salience ℓ/n (n=10)
Intelligent	3.75	0.38
Wise	3.67	0.37
Quiet	3.67	0.37
Kind	3.08	0.31
Reflective	1.74	0.17
Creative	1.67	0.17
Hard Worker	1.17	0.12

Figure 3. Men's basket.

Figure 4. Drum.

Hunting Play Among San Children

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Creation and sharing of images

This study focuses on children's behavior in creating and sharing a new image through playing. I have carried out a comparative study of children's play between Japanese children in kindergarten and children of the San, who are hunter-gatherers living in Botswana.

Childhood and children's play are social and cultural phenomena, as many researchers have pointed out since Phillipe Ariés. Nevertheless, some common points can be seen in children's play (Kawabe, 2005):

1. Children will continue to play with concentration for a certain period.
2. Each child has a certain image about what they are doing when playing.
3. They voluntarily approach the environment to make play equipment and the space needed for playing.
4. They share their play image with others through materials, space and language.

Observation of children in kindergarten

I have been conducting a comparative study on children's play activities at the H Kindergarten in Seto, Japan, since April 2011.

The results of observations at the Japanese kindergarten are briefly summarized as follows:

(1) Playground play

Various types of play activities were observed in the playground, such as: walking on stilts, playing soccer, rolling tires, playing tag (cops and robbers), dressing up in costumes, playing with provided toys (horizontal bars, climbing ladders, horse-type toys, jungle gym), playing in the Wendy house or in dens of large tires, playing with flowers, making "mud balls", playing in the sandpit, observing insects in a box.

(2) Sandpit play

In Japan, "sandpits" are so popular for children's play areas that every kindergarten, nursery school and park for children has a sandpit. By playing in a sandpit, children develop their imagination and creativity. In sandpits, children make "sand houses" and "mountains," and also dig holes for "rivers and lakes," so that they can make a "town." Not only do they play at building things, they also play house by imagining the sand as "food."

(3) Sharing images

The children who are playing together in the sandpit share the images of the "towns" and "landscapes." It is important to clarify how they can share these images.

(4) Transmission of skills from children to children

In that kindergarten, children make "mud balls" from sand, soil and water. The teachers do not teach how to make these, the skills are transmitted from older to younger children.

A field survey of children's play and learning among the San in Botswana

I conducted a field survey of children's play among the San in Botswana from 11 February to 7 March, 2012. The research points are as follows:

1. Variations of children's play and the sex-age composition of their games.

2. Transmission of skills for hunting and gathering from older to younger children.

3. Comparing the San children's "play imitating adults or others' behavior" with Japanese children's.

In this research I focused on mimicking behavior. In general imitation has a model and imitation is a behavior in which a person copies the model. But often children's imitation play does not need a model. Their imagination can go beyond the model. Sometimes they share their imaginations and create a new kind of play. I divide imitation into two types.

(1) Copying the model

This type of imitation is found in transmission of techniques. When children learn how to use a knife and how to make a bow and arrow, a spear, or a snare, they observe adults who are making these things and they copy the adults' actions exactly. But it is not necessary for the children and adults (the models) to be together on the spot. Sometimes children will make a snare alone after they have observed adults' behavior and remember it.

Adults do not directly teach children how to use a knife. It is the older boys who transmit knife technique to the younger ones. Neither do the older boys specifically teach the technique but they help the younger boys when they reach an impasse in making some hunting tools or toys. The way of "helping" is simply an older boy alternates making them himself and continuing to make what a younger boy has begun until it is complete. This "alternating maker" is often seen even among adults. They say "alternating making" is "enabling the owner (who first began to make it) to make something."

(2) Sharing imagination and creating new play

"*Gokko asobi*" (in Japanese) is typical of this imitation play. *Gokko asobi* or "pretend play" involves imitating someone, usually a mother, a father and a baby, while doing role play with other children. The model might be their own family, but often children act out a "typical" or "ideal" family. It is a stereotype that goes beyond the real family.

This year, I found a new type of play among San children. It is "hunting play."

Around ten years ago, children aged four to 14 played hunting games. They had little bow and arrows and they actually hunted little birds and lizards. Everything was small and not serious. So it was a kind of play.

Now they mimic the whole process of hunting on horseback. First they make horses and spears from tree branches and leaves. Next they take the roles of "hunter on horseback" and "game animals." Then they perform each role. The "hunters" (usually older children) chase down the "game" (usually younger children) and they grapple and fight for a few minutes. Finally the "hunter" kills the "game" with the "spear."

They also mimic butchering the game animal. They reproduce the actions of cutting the "skin", then skinning and jointing the animal.

Recently real hunting activities have declined and the chances for children to observe hunting have also been reduced. They reproduce hunting scenes from hearing adults talk about past hunts and observing the butchering of cattle. They devise new types of play and share them. Finally they create a new imaginary world.

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Play Activities and Cultural Transmission Among Hunter-Gatherer Children: The Case of the Baka in Cameroon

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Purpose of the research

In order to clarify the causes of the replacement of Neanderthals by *Homo sapiens* in aspects of cultural transmission and culture change, it is necessary to examine the differences between learning behaviors and abilities of Neanderthals and those of *Homo sapiens*.

It has been pointed that hunting-gathering societies have neither educational institutions nor educational behaviors among their children. Hunter-gatherer children have their own culture, which is connected to the transmission of hunting-gathering culture. These were the results of my anthropological research in 1996-1998 among Baka children in the tropical rain forests in the East Region of the Republic of Cameroon (Kamei, 2010).

Fifteen years later, with the further spread of schooling and the introduction of restrictions on hunting, how have children's culture and life changed? Are the characteristics of cultural transmission in foraging societies still maintained? This research aims to collect ethnographic data on children's daily activities including play, hunting, gathering, fishing, housework and so on. It also aims to describe the system of cultural transmission through this age group as one of the characteristics of foraging societies.

Methods

[Period] March 2012 (5 days); August-September 2012 (14 days)

[Field site] Settlements of Baka hunter-gatherers in the East Region, Republic of Cameroon (Figure 1)

[Methods] Participant observation and interviews with Baka children. Experimental methods on learning and teaching activities were also adopted.

Results

Through participant observation and interviews among Baka children, the following points were found.

(1) School attendance rates have increased among both boys and girls, and consciousness of schooling is already shared among the majority of parents (Table 1).

(2) Play and subsistence activities (hunting, gathering and fishing) conducted by boys and girls observed out of school have not changed.

(3) Social and cultural changes among adults partly affect children's activities, but do not affect their way of learning.

Discussion

The results show that in the past fifteen years, children's culture and life have not changed. Observation and imitation are still the essential ways of learning among children. As before, it is rare to observe positive teaching activities among them. The characteristics of foraging societies "without education" are still maintained.

These comparative data show us both robust and vulnerable aspects of the way of life and behaviors of hunter-gatherer children. Together with these observations, a "learning model of hunter-gatherer children" will be presented in order to discuss the

nature of "educational activities" by human beings. It is hoped that this will contribute to clarifying the causes of culture changes and innovations that led to the replacement of Neanderthals by *Homo sapiens*.

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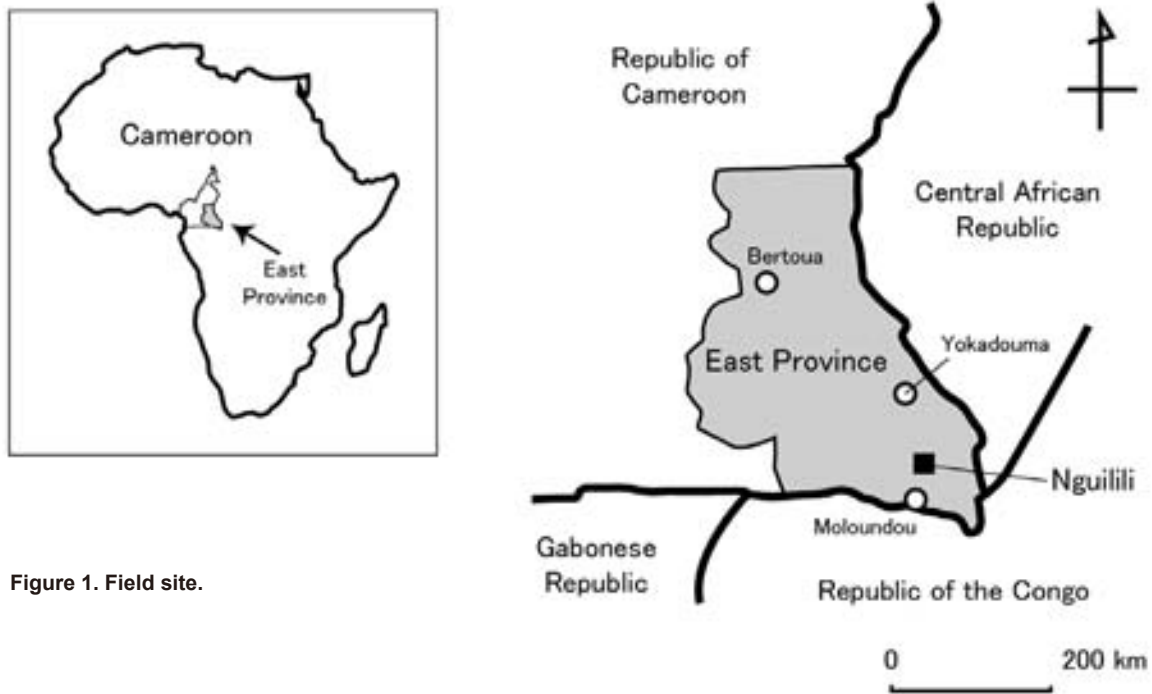

Figure 1. Field site.

Table 1. Number of Baka children of school age (6-12 y.o., March 2012).

	In school (a)	Not in school	Total (b)	School attendance rate (a)/(b)×100%
Boys	31	28	59	53%
Girls	30	19	49	61%
Total	61	47	108	56%

Cognitive Flexibility and Making Objects in Baka Children

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Relying on Piaget's theory, Pellegrini (2009) pointed that children's cognitive development could been rooting in their sensorimotor interactions with objects. Through repeated interactions with objects, children construct representations for those objects (Pellegrini, 2009). These representations would come to express in their making objects. Some aspects of children's cognitive development and their ongoing interests are reflected in their making objects. And doing in these activities may develop their creativity. Child's behavior with objects has been studied from the view point of exploration, play, construction, and tool use (Bock, 2005). Children would often be absorbed in making objects for their play, such as making a basket out of leaves. I think these activities affect later their creativity and cognitive flexibility.

In recent researches in developmental psychology, cognitive flexibility is defined that a child could switch his strategy to solute the tasks. For example the DCCS (Dimensional Change Card Sorting; Zelazo, 2006) task assesses the capacity to flexibly shift between two sorting rules based on color and shape. Kloo, Perner, Aichhorn, & Schmidhuber (2010) suggested that we had to distinguish two different kinds, response flexibility and representational flexibility. Making objects also requires children's cognitive flexibility, especially representational flexibility. I want to demonstrate the creativity of the children who are nurtured in hunter-gathering societies. So in this study I observed Baka children's making objects in their daily life and speculated on their cognitive flexibility through their making objects.

1. Method

I conducted the observational research on children's making objects in East Cameroun between 13th and 18th of August in 2012, I visited five Baka Pygmies villages and conducted observation on Baka children's making objects and playing with objects in their site. I observed about two hours in the morning and two hours in the afternoon every day. The children's activities with objects were recorded by a SONY Handy Cam.

2. Results

Making objects for play were very often observed in Baka children. But the scene of making objects was observed almost in solitary play (Figures 1, 2 and 4). And making objects and constructing objects were observed in collaborative symbolic play (Figure 3). This play was observed particularly in the girls. They used object substitution for many purposes to simulate the real cooking scene. Some children incorporate 'newcomer' materials to their sites into making objects for play (Figures 1 and 2). Those products then were used in other children in the same site. And it came to be elaborated by them. Figure 2 shows that the boy used concave space on the ground as pretending a river bridged it with wood. It seemed to represent the real scene that a car with loading went on the bridge.

Figure 4 shows solitary constructing objects of 4 year old boy. The boy in Figure 4 was concentrated in attaching some pieces of wood to the wheel. Children would use those broken parts of entities

for their objects making. Figure 5 shows that the boy in the picture making a steering while using broken parts of a motorcycle.

3. Discussion

Until about 3 years old, children engaged in sensorimotor interactions with materials around them. Around 4 years old, children would make objects. But these observations reported here were very often and making objects were observed almost in a child's solitary situation.

Sex differences were also observed. Girls making and constructing objects were observed in their collaborative symbolic play, which was similar to cooking and preparing meals that woman engaged. Those activities were interpreted playful uses of objects as simulations. And object substitution in that play might increase their cognitive flexibility. On the other hand, boys preferred making objects for pretending as cars, trucks and motorcycle. For that activity new materials tended to incorporate with leaves, stones, wood, and string. It was thought that in that construction of object their cognitive flexibility may be enhanced.

Kamei (2009) reported materials that Baka children used for their play. And he emphasized that's richness and creativity of them using those materials. Kloo, Perner, Aichhorn, & Schmidhuber (2010) demonstrated that 'Flexibility is a key competency in daily life.' We can see Baka Pygmies children's development cognitive flexibility in their daily making objects, object substitutions and using broken parts of entities. In this research I noticed new materials might affect their development. Koyama (2012) pointed that younger Baka children showed their intuition and ability of representation in responding to signs of visual reception tasks. The development of representation in responding to signs of visual reception tasks parallels that of making objects. Intuition and ability of representation might be related to the development of their object making. This research impressed on me that children's development of cognitive flexibility are based on their intentionality to real world around them.

Figure 1. Making an object with a can.

Figure 2. Making river and its bridge with wood.

Figure 3. Making objects in girl's collaborative symbolic play.

Figure 4. Constructing objects with a wheel and wood.

Figure 5. Using broken parts of a motorcycle.

The Art of Patience as the Emotional Basis for Creativity and Cultural Learning: Learning and Ecological Adaptation Among the Canadian Inuit

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Any human individual is born into each society and begins its lifelong learning process with social learning of each culture. In this sense, social learning of cultures can be said to be the base for any kinds of learning for *Homo sapiens*.

Above all, as pointed out by Tomasello (1999), 'cultural learning,' including 'imitating learning,' 'instructed learning' and 'collaborative learning,' plays the most important role in the learning process of *Homo sapiens*. This is because cultural learning is essential to its species-unique modes of cultural transmission, that is 'cumulative cultural evolution,' the process of which 'requires not only creative invention but also, and just as importantly, faithful social transmission that can work as a ratchet to prevent slippage backward — so that the newly invented artifact or practice preserves its new and improved form at least somewhat faithfully until a further modification or improvement comes along.' (Tomasello, 1999: 5) If so, how does human individual learn each culture and improve what s/he has learned by cultural learning?

In order to understand the mechanism of 'cumulative cultural evolution,' I conducted ethnographical research on the learning process of Inuit children at Kugaaruk, Nunavut, Canada, between the 8th and 27th of March in 2011, between the 12th and 27th of March and between the 17th of August and the 7th of September in 2012. The result of these researches is as follows.

Kugaaruk, Nunavut Territory, Canada

one of extended families in Kugaaruk

narwhale hunting

a teenager with his harpoon

uncle and niece

a girl learning the wayto dissect narwhale

adults and children at home

a boy hunting caribou

1) The flexible and creative tactics, which are considered to be the essence of Inuit Qaujimajatuqangit (Inuit Knowledge), are learned by experience of overcoming difficulties with persevering and patient efforts in everyday life and subsistence activities.

2) Inuit children are exposed to adults' playful teasing in everyday life and learn the art of patience as the base for cultural learning and creative individual learning through their experience of being in a dilemma posed by the teasing.

3) It is crucially important to investigate how Inuit adults deal their children in their everyday life in order to understand how Inuit children learn the emotional attitudes essential to flexible and creative individual learning and cultural learning.

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Communicative Musicality and Learning in Caregiver-Child Interactions Among the San of North-Central Namibia

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In this paper, I will discuss the role of musicality for promoting early socialization and learning in the course of caregiver-child interactions among a group of the San (!Xun), a post-hunter-gatherer people living in the north-central part of Namibia. Musicality introduces the structure of "intersubjective time" (Gratier & Apter-Danon, 2009) as a means of achieving mutual understanding in caregiver-child interactions. This facilitates cooperative coordination of attention, posture, position, and affect among participants. This coordination communicates what the participant should and should not do and thereby provides children with the ground for socialization and learning in the given society. This process prepares a context in which actions that fit with culturally shared values are put into practice in everyday life. The communicative musicality perspective (Malloch & Trevarthen, 2009) give a powerful tool to analyze how such process is going to be organized.

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Malloch, S. & Trevarthen, C. (2009) Musicality: Communicating the vitality and interests of life. In S. Malloch & C. Trevarthen (Eds.), *Communicative musicality: Exploring the basis of human companionship* (pp. 1-11). Oxford University Press.

The Resilience of Pygmy Children– On Their Drawings about Favorite Things

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Introduction

"Resilience" is a key word for understanding how to cope with extreme stress such as the trauma of child abuse or serious experience of war and disaster. In fact, although some victims suffer from PTSD and some of them develop a personality disorder after growing up, some of them survive without any problems. The last group might be successfully surviving as they are flexible and capable of learning from their difficult condition. The strength of the flexible attitude is "resilience", or in another word willowy. This psychological concept "resilience" might be applied for considering the superiority of *Homo sapiens*, because of their ability to overcome a difficult environment, including temperature, food and enemy issues over a long history. I suggest that the resilience of *Homo sapiens*, examining the drawings of hunter-gathers Pigmy Children who might be a pure type of *Homo sapiens*.

Participants

31 Baka Pigmy Children in Cameroon (25 boys and 6 girls, age ranged from 5 to 15 years old, the data collected in 2011 summer)

Procedure

The children were asked to draw their favorite things on the paper with tools such as pencil, colored pen and pastel crayon, which they could choose.

Results

1) Drawing process and attitude

They chose paper and tools that were set up in front of them. Then, according to my instruction, they started to draw spontaneously without hesitation or help from others. After making images they pointed and named their favorite things on the paper. Finally, they told me that they had enjoyed drawing very much.

2) Drawing itself

Drawing style: 1 constructed painting (Figure 1), 15 imaginary x-ray paintings (Figure 2), 10 incomplete gestalt paintings including 2 head-feet representations (Figure 3), 17 multiple viewpoint paintings, 18 kinetic paintings (Figure 4), 18 energetic paintings and 2 skillful and artistic paintings (Figure 5).

Drawing content (rate of drawing): vehicle and plane 80.6%, human being 74.1%, food (edible animals and fruits) 64.5%, plants 61.2%, house including a traditional tent mongle 38.7%, tools (pump, rifle, traditional knife, drum, pan, umbrella, glasses, wooden boat and table) 38.7%, animal 32.2%, fish 32.2%, soccer ball 29.0%, electrical appliances (T.V., DVD, mobile phone, antenna etc.) 19.3%, sun, moon and stars 19.3%, letters and numbers 16.1%, cloth 6.4%, and national flag 6.4%.

Discussion

The favorite things drawings of Pigmy children seem to reveal the resilience through their drawing process and drawing itself. For example, one of the resilience factors, "Productive activity" (Klohnen, 1996) might be shown by their active attitude for an unfamiliar situation and kinetic and energetic drawing style. The drawing content also indicates

"Productive activity". Namely, "shot with rifle" and "kick a soccer ball" in the drawings are important activities for their life. "Hand" is needed to attain something and "food" is the desire to eat for sustaining life. All these figures might reveal "Productive activity". Moreover, the content shows other component factors of the resilience. For example, a high rate of "human being" might mean friendship with others or staring at themselves and so it might indicate the resilience factor, "Insight and warmth". "Vehicle, plane and electrical appliances", which belong to a different culture, are far from the real life for Pigmy children, but they are fond of such unfamiliar things and expect to obtain them in future. The children can imagine how the new and strange things are desirable. Likewise, they are in favor of both their own and different culture related things in their drawings. This openness might mean the resilience factor, "Confident Optimism". The last resilience factor by Klohnen, "skilled expressiveness" is shown by the art activity for all of them, especially, by two skillful and artistic paintings.

Conclusion

Pigmy children can be considered to be resilient people. Through their "resilience", i.e., an acceptable and flexible attitude to a transitional and critical situation, I speculate that *Homo sapiens* have been thriving in the face of adversity over a long history.

Figure 1. Constructed painting. A (9yr. boy). Car with antenna, house, person, lizard, dog, mouse, trees, rifle and birds

Figure 2. X-ray painting. B (10yr. boy). Car, house, person, ball, pump, hand, fish, cook, tomato and flower

Figure 3. Incomplete gestalt painting.C (11yr. girl). House, persons, cook, car, table and tree

Figure 4. Kinetic painting. D (7yr. boy): Man with rifle, persons, cook, car, cacao, hand

Figure 5. Artistic painting. E (12yr. boy). Helicopter, motorbike, radio, DVD, ball, boat, mobile phone and moon

Estimation of the Period of Childhood and Child Growth Characteristics of Pygmy Hunter-Gatherers in Southeast Cameroon

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Introduction

Pygmy hunter-gatherers, who are known as the original inhabitants of Central African rainforest, have the smallest stature in the world. Their short stature had been attracted by many anthropologists and human biologists, and so their growth pattern as the mechanism of their physique was thought as the important theme of human biology which can provide key knowledge of human evolution. This study aimed at characterizing the growth pattern of pygmy hunter-gatherers by using mathematical method and comparing with world populations.

Materials and methods

A cross-sectional anthropometric measurements including height and weight were conducted on 626 Baka children (349 boys and 277 girls) from 62 semi-settlement villages ranged wide area in southeast Cameroon. The ages of participants were estimated to the nearest 0.5 years by birth-reordering, interviewing and event matching.

The smoothed growth and height velocity curves were derived from applying Preece-Baines model I, which is one of the most common mathematical human growth models. The biological parameters (e.g. ATO: the onset of adolescent growth spurt, PHV: velocity at peak height velocity) were calculated from mathematical parameters of function, and compared with 5 populations (Europe, Africa, Asia, Australia, South America) from previous studies.

The nutritional status which influences the child growth, was assessed by classification of participant's BMI using sex-age cut-offs proposed by International Obesity Task Force.

Results and discussion

The adolescent growth spurt of Baka children were characterized as strongly suppressed than previously studied children (Figures 1 and 2; solid bold lines).

The period of adolescent growth spurt, which was indicated as from age at take-off (ATO) to peak height velocity (PHV) was almost similar among all groups for both sexes (Tables 1 and 2). It is considered to be reflected the good nutritional status of Baka children as well as over 80% of participants had normal ranged BMI. This result showed that the periods of adolescent and also the period of childhood were similar among modern human.

There was a remarkable characteristic about growth tempos of Baka children during early childhood. Although adult height were greatly difference among Baka and other groups both sexes (boys: 11.6 - 20.5 cm, girls: 4.1 - 15.8 cm), the amounts of height gain after the onset of adolescent growth spurt were quite similar among six populations including Baka children (Tables 1 and 2). It may suggest that the height gain during early childhood is much less, and the growth tempo of Baka children was slow.
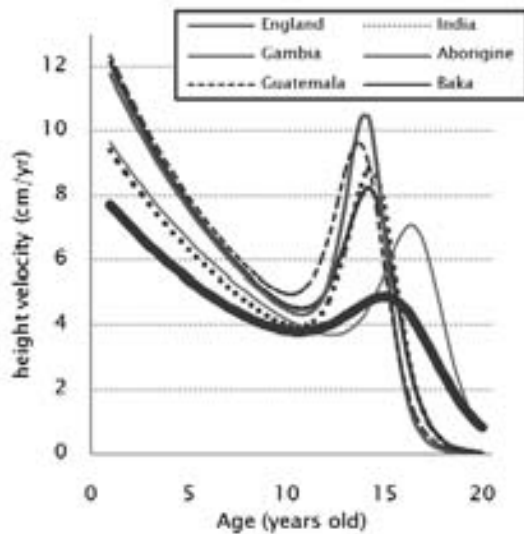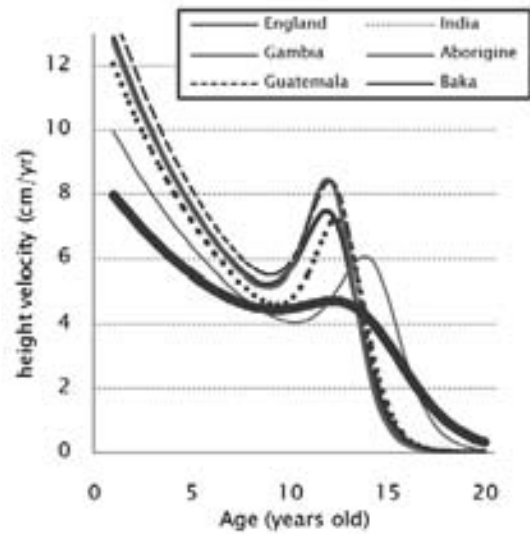
Figure 1. Height velocity curves of boys.

Figure 2. Height velocity curves of girls.

Table 1. Biological parameters of Baka compared to previous studies (boys).

Boys	Baka	British	India	Guatemala	Aborigine	Gambia
Adult Height	154.1	174.6	165.7	177.1	172.1	170.7
Age at TO	10.67	10.75	10.62	10.71	10.80	12.29
Age at PHV	14.98	14.19	14.30	14.21	14.01	16.37
VTO	3.80	4.52	3.95	5.02	4.34	3.70
PHV	4.88	8.24	8.84	9.40	10.59	7.08
HtTO-AH	34.77	35.62	36.27	40.60	36.13	35.13
Ht inc TO-PHV	18.42	20.62	21.26	23.55	21.21	20.42
Ht inc PHV-AH	16.35	15.00	15.02	17.04	14.92	14.71

Table 2. Biological parameters of Baka compared to previous studies (girls).

Girls	Baka	British	India	Guatemala	Aborigine	Gambia
Adult Height	147.6	163.4	151.7	163.4	162.9	158.7
Age at TO	9.30	8.89	9.37	8.86	8.91	10.27
Age at PHV	12.24	11.90	12.42	11.92	11.95	13.84
VTO	4.46	5.24	4.61	5.13	5.13	4.05
PHV	4.71	7.49	7.24	7.47	8.49	6.06
HtTO-AH	33.35	33.63	30.67	33.57	34.44	31.13
Ht inc TO-PHV	13.42	18.63	17.38	18.69	19.69	17.45
Ht inc PHV-AH	19.93	15.00	13.29	14.88	14.74	13.68

The Effects of Cross-Boundary Rituals on Cultural Diversity

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Introduction

In this talk, I examine how cross-boundary rituals, through which members of different groups communicate with one another, affect cultural diversity in modern human groups. In general, mass migration destroys local minority culture, which may also have been the case in prehistoric times. Cross-boundary rituals should have counteracted the negative effect of migration and maintained the diversity of local cultures. To test this hypothesis, I built an agent-based model (ABM) simulation. This model is a different version of the one described by Horiuchi and Kubota in an oral presentation.

Methods

The ABM assumes N agents and M groups. The groups are arranged along circular stepping-stones. N / M agents belong to each group under the initial condition. Culture consists of K independent traits, represented as the vector $(c_i, 1, c_i, 2, …, c_i, K)$ for agent i. If the agent knows, or does not know, the jth cultural trait c_i, j is 1 or 0, respectively. C_i denotes the total number of cultural traits that agent i knows, which can be expressed as $C_i = \Sigma_j c_i, j$. D denotes the total number of remaining cultural traits which are known by at least one agent. The range is $0 \leq C_i, D \leq K$. At the initial condition, agents of group j know only the jth cultural trait, so $C_i = 1$ and $D = M$. Here cultural trait j is the endemic knowledge of group j. For simplicity, the model sets parameters as $N = 200$, $M = K = 20$. The total number of groups equals the total number of cultural traits, and the set of all groups is matched against the set of all cultural traits.

The simulation iterates turns composed of two steps: a within-boundary ritual and a cross-boundary ritual. In the within-boundary ritual, two agents in the same group are selected. One copies a randomly selected cultural trait from the other. In the cross-boundary ritual, an agent checks her own group and its nearest 2L groups ($0 \leq L \leq M/2$). Among these, she selects the group with the largest average value of C_i. She then visits that group, copies a cultural trait from an agent in that group, and goes backs to her own group. In these two processes, agents may learn or forget a cultural trait, when counterparts do or do not know the trait. An agent migrates between groups in Q turns ($10^{-2} \leq Q \leq 10^6$). When Q is smaller than 1, 1 / Q agents migrate between groups for each turn.

I used the parameter D as the index of cultural diversity. The purpose of this simulation was to investigate the average value of D for 30 trials under each condition of (L, Q) after enough time passed (preliminary simulations indicated that 300,000 turns were sufficient).

Results

When $L = 0$, the value of D produced a decreasing curve along the value of log Q. When $L = 1$, the value of D showed a U-shaped curve along the value of log Q; the values of D were significantly higher when agents migrated more often ($1 \geq \log Q \geq -2$) than when agents migrated less often ($5 \geq \log Q \geq 4$) (post hoc Kruskal-Wallis test, $P < 0.001$). Mass migrations of agents left fewer cultural traits when agents did not carry out cross-boundary rituals; more cultural

traits remained due to mass migrations when agents did carry out cross-boundary rituals (Figure 1).

When log Q = 2, the value of D increased along the value of the L curve. When the value of log Q = 0, the value of D showed an inverse U-shaped curve along the value of L; when L = 10, the values of D were significantly smaller than when $1 \leq L \leq 9$ (post hoc Kruskal-Wallis test, P < 0.001). The greatest cross-boundary rituals did not always maintain high cultural diversity when agents frequently migrated between groups (Figure 2).

Conclusion

If agents perform within-boundary rituals only, and migrate between groups, each cultural trait should disappear from the world by a probability of 19/20 once enough time has passed. On average, only one cultural trait should remain (D = 1). More cultural traits will remain in the world if cross-boundary rituals are also performed. It is presumed that Neanderthals maintained a monoculture over the whole European continent, whereas modern humans propagated cultural diversity. Different local cultures were sometimes united and evolved into a more elaborate culture. In both *Homo* species, individuals migrated between groups. But only among modern humans were cross-boundary rituals enacted. Cross-boundary rituals could have affected the cultural accumulation of modern human groups and resulted in their replacing Neanderthals.
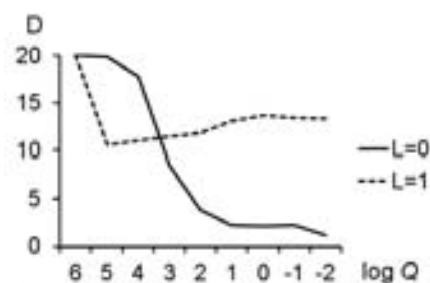
Figure 1. Without cross-boundary ritual (*L* = 0), few cultural traits remain (small *D*) when agents frequently migrate between groups (small log *Q*). With cross-boundary ritual (*L* = 1), more cultural traits remain (large *D*) if agents frequently migrate between groups (small log *Q*).
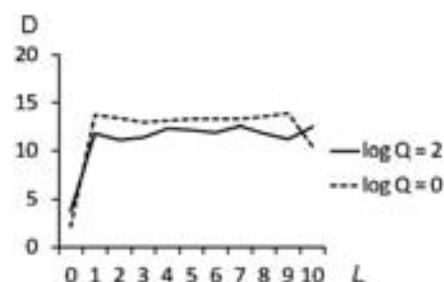
Figure 2. When agents frequently migrate between groups (log *Q* = 2), more cultural traits remain (large *D*) when many groups engage in cross-boundary ritual (large *L*). When agents frequently migrate between groups (log *Q* = 0), fewer cultural traits remain (small *D*) if all groups operate cross-boundary ritual (*L* = 10, the complete graph).

Effect of a Heterogeneous Environment on Range Expansion of Individual and Social Learners

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In the previous paper (Wakano et al., 2011), we investigated the spatial population dynamics of individual and social learners by a reaction-diffusion model. In the model, it is assumed that social learners may fail to find a conspecific from which to copy the adaptive behavior when the population density is low. By analyzing the model, we have following results. When individual and social learners are expanding into empty space, traveling waves are formed. Although the space is environmentally homogeneous, individual learners can survive near the front of the traveling waves.

In this paper, we consider the effects of spatial heterogeneity on range expansion of individual and social learners by the same type of the previous model except the space is environmentally heterogeneous. The space consists of different types of environments, each other (Figure 1). In the heterogeneous environment, correct social learners become wrong learners by moving other type of environments. Individual learners quickly learn and adapt their behavior to new type of environment. Therefore, for the individual learners it is likely that the environment is uniform.

where X_i is population density of social learners which behave correctly at type-i environment, Y is population density of social learners which cannot correctly behave at everywhere and Z is population density of individual learners. r is the growth rate, A is the attenuation rate, m is the competition coefficient, s is the mortality cost of wrong behavior and c is the exogenous cost of individual learning, and D is the diffusion coefficient.

After analyzing the model, we can get results that the population of individual learner can be easily maintained in heterogeneous environment than uniform environment at the front of expanding range.

Reference

Wakano, J.Y., Kawasaki, K., Shigesada, N. and Aoki, K., 2011. Coexistence of individual and social learners during range expansion. *Theor. Popul.* Biol. 80: 132–140.

Mathematical model is as follows:

$$\frac{\partial X_i}{\partial t} = r(X_T + Y)\frac{X_i + \phi_i(x)Z}{A+N} - (mN + (1-\phi_i(x))s)X_i + D\frac{\partial^2 X_i}{\partial x^2}$$

$$\frac{\partial Y}{\partial t} = r(x)(X + Y)\frac{A + X}{A+N} - (mN + s)Y + D\frac{\partial^2 Y}{\partial x^2}$$

$$\frac{\partial Z}{\partial t} = rZ - (mN + c)Z + D\frac{\partial^2 Z}{\partial x^2}$$

$$X_T = X_1 + X_2 + \cdots + X_n, \quad N = X_T + Y + Z$$

$$\phi_i(x) = \begin{cases} 1 & (x \text{ in type-}i \text{ environment}) \\ 0 & (x \text{ in other type environment}) \end{cases}$$

Figure1. Heterogeneous environments.
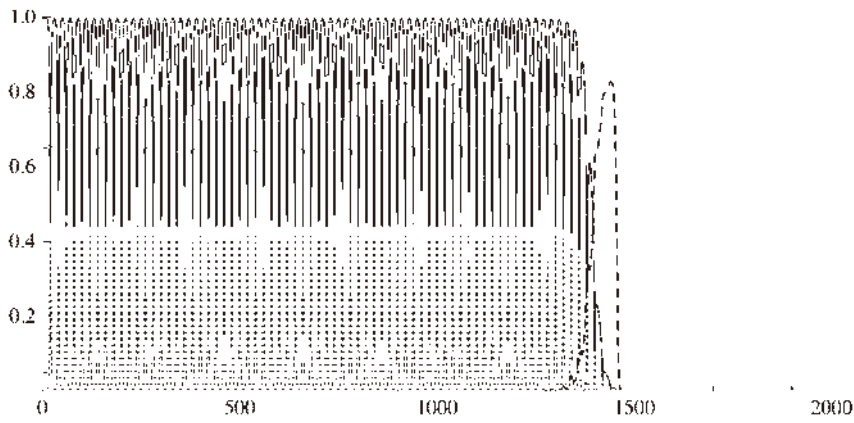
Figure 2. Numerical result for the invasion of social and individual learners into empty space. $r=m=D=1$, $c=0.16$, $s=0.5$ and $L=20$. Solid line: social learner behaving correctly. Dotted line: social learner behaving wrongly. Break line: individual learner.

Dispersals of Modern Humans: Inferences from Genome Diversity Data

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Introduction

We face exciting times in population genomics. Because of advances in DNA technologies, in particular, DNA microarrays and next-generation DNA sequencers, we have revealed genetic structures of human populations at an unprecedented resolution. In addition, various statistical techniques have been developed so far to infer demographic history of populations from genomic data. However, it is still difficult to reconstruct a complicated demographic history of a large number of populations. In this study, I focused on 1) phylogenetic analysis, 2) principal component analysis (PCA), and 3) model-based clustering analysis, and aimed to learn how to interpret the results of these genetic analyses using computer simulations. Such empirical understandings of statistical methods must facilitate to set a complex demographic model to be tested.

Methods

Coalescent simulations assuming multiple models were performed using a program, msms. We set an in-group consisting of nine subpopulations (SP1-9) and two out-groups (O1, O2) in the following models (Figure 1A): cascaded splits model (S), migration model (M), old admixture model (OA), and recent admixture model (RA). We sampled 20 sequences from each out-group or subpopulation, and obtained 220 sequences in total. The number of replications was more than 10,000 times. One SNP with the minor allele frequency no less than 10% was randomly collected for each replication, and we generated 220 haploid genome data that contain 10,000 independent SNPs. Finally, two haploids were paired to construct diploid genome data. Nei's minimum genetic distance was calculated between every pair of populations. From the distance matrix of populations, we constructed NJ tree and NN network using SplitsTree4, although these phylogenetic analyses can be applied to the distances between individuals. Individual genotype data were applied to PCA using Eigensoft 3.0. A model-based clustering analysis was also performed using ADMIXTURE.

Results and Discussion

Phylogenetic analysis, PCA, and clustering analysis each shows some specific patterns depending on the demographic scenarios (Figure 1B-D). In addition, I demonstrated a possibility that even mathematical artifacts in these analyses can give a cue for discriminating scenarios such as population split, migration, and admixture. In recent population genetics, the model-based Bayesian approach is widely adopted to know the complex demographic history, in which we need to try a model for testing its validity. If there are a number of focal populations and thus a number of possibilities, it may be difficult to find the appropriate model. Even in such a case, the statistical methods taken up in this study, compensating each other, can play crucial roles in the modeling of possible demographic scenarios. The empirical understandings of these statistical methods will be useful to pare down possible candidates of the past demographic history.
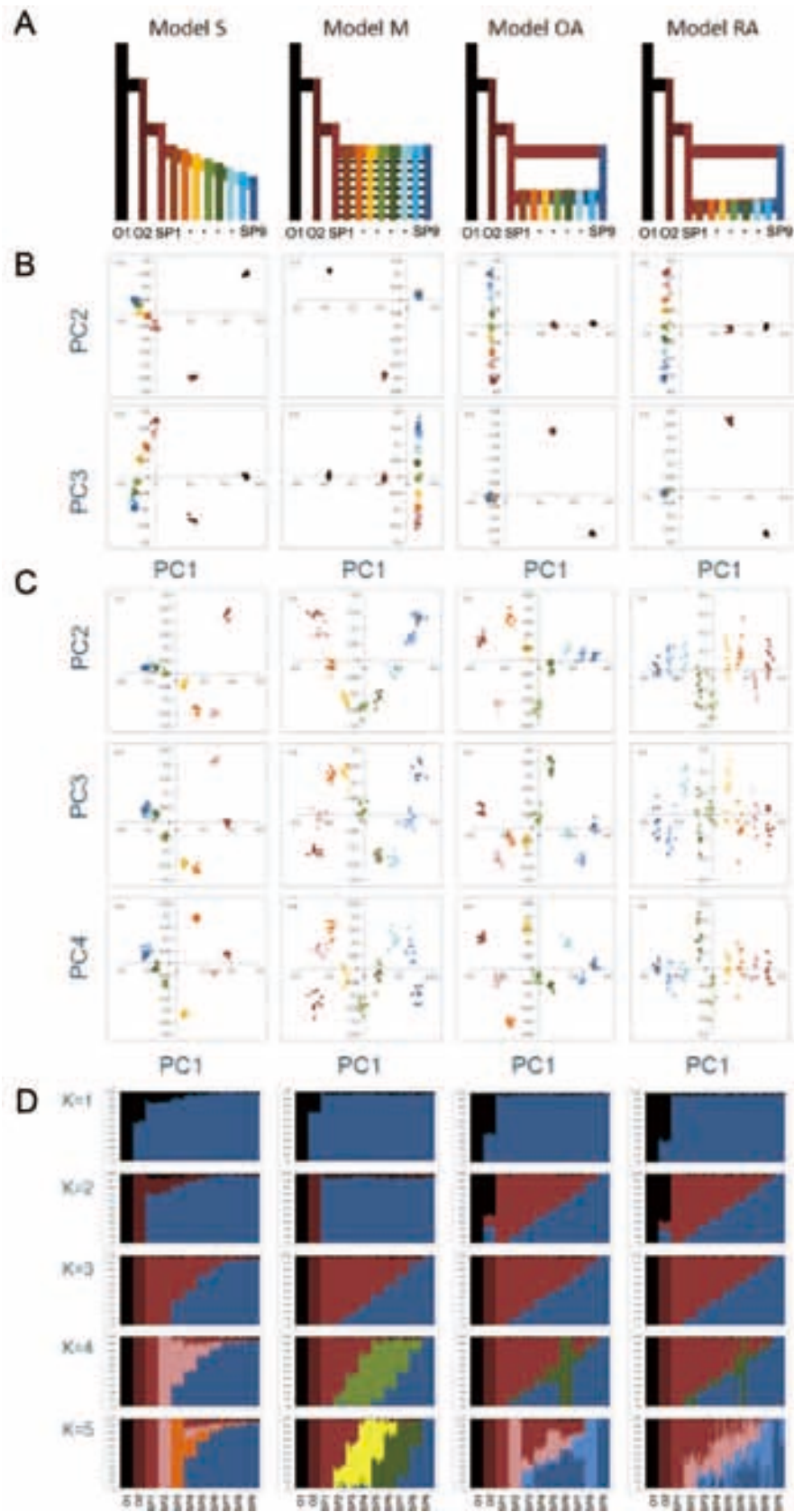
Figure 1. Simulation study. (A) Simulation models. (B-C)
Results of PCA with outgroups (B) and without outgroups
(C). (D) Results of clustering analysis.

A Simulation Study on the Replacement of Neanderthals by Modern Humans in Europe: Implications of Climate Change, Cultural Diversification, and the Shape of the Continent

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It is said that *Homo sapiens* appeared in Africa roughly 200k years ago and replaced Neanderthals, who had been occupying Europe, roughly 40-30k years ago. There are a variety of hypotheses as to the cause of the replacement, and some of them emphasize the roles of climate change, competitive exclusion, and inherent difference in learning abilities between the two species (the "learning hypothesis"). As is well known, the rate of cultural evolution and cultural diversity apparently increased in the Upper Paleolithic in which the replacement supposedly occurred. In addition, it is said that Neanderthals survived longer in the Iberian Peninsula than in other areas of Europe. In this study, I construct a spatially explicit model to simulate the replacement of Neanderthals by modern humans based on multiple causes, including climate change and difference in learning abilities.

I consider a virtual lattice space consisting of 80x80=6,400 cells. The cells are categorized into water and land areas, where the latter are further categorized into forests and plains. The vegetation state of each land area stochastically changes with the course of time following a discrete-time Markov process. For simplicity the temperature is assumed to depend on latitude but not on longitude. I assume that the transition probability from a forest to a plain decreases with temperature, while the probability of the reverse transition increases with temperature. The temperature varies cyclically with time, imitating highly variable glacial climate.

I consider population dynamics of two virtual species, which I call for simplicity Neanderthals and modern humans. Each land area can accommodate up to N human bands. Each band may bear up to n distinct techniques useful in forests and likewise up to n techniques useful in plains. In every time step, the following events take place in order: Markovian vegetation transitions, reproduction, death of bands, and innovation and loss of techniques. In the reproduction phase, each band produces a daughter band with probability B. The mother band stays in the current area. The daughter band, on the other hand, stays in the natal area with probability 1-m and disperses to each of eight adjacent areas (i.e. Moore neighborhood) with probability m/8. The daughter band successfully settles with probability 1-x/N, where x is the number of preexisting bands in the destination area. The daughter band inherits all the techniques of the parent band. In the death stage, each band dies with a probability dependent on the local temperature and the technological state of the band. I assume that the death rate of a band decreases with the number of techniques that are useful in the current environment. In the stage of innovation and loss of techniques, each band may lose techniques with a constant rate. I suppose, for simplicity, that Neanderthals are very conservative, so that they never forget techniques. Likewise, modern humans never forget techniques that are currently in use. However, they may forget techniques that are currently not in use. For simplicity, I suppose that Neanderthals are not able to innovate new techniques. Modern humans innovate useful techniques (e.g. forest-

adapted techniques when in forests) at a constant rate. To simulate the replacement of Neanderthals by modern humans in Europe, the distribution of land areas was generated from a real map of the world. Neanderthals were initially distributed over mid-latitude areas with density 0.1, and modern humans over low-latitude areas with the same density.

Simulations have shown that the replacement of Neanderthals by modern humans typically proceeds in three distinct phases (Figures 1 and 2). In the first phase, modern humans cannot travel north beyond a certain latitude because Neanderthals basically fare better in such cold areas. Since the distribution of modern humans is mostly confined within permanent forest areas, their population does not fluctuate much despite variable climate. Neanderthals, on the other hand, suffer from rapid vegetation shifts associated with climate change, and their population largely fluctuates.

In the second phase, some of modern humans at the northern edge of their distribution, who occasionally undergo loss of forests, fortunately acquire some plain-adapted techniques and successfully settle in northern plains. This causes a population explosion of modern humans in mid- and high-latitude areas. In mid-latitude areas, modern humans alternately acquire and lose forest- and plain-adapted techniques, surviving variable vegetation conditions. Because loss and acquirement of techniques are stochastic, cultures in distant places develop more or less dependently but asynchronously. As a result, cultural diversity flourishes in mid-latitude areas, where environments are most variable. While modern humans rapidly spread over mid-latitude areas, Neanderthals are swept out of there and become confined within small refuge areas, such as the Iberian Peninsula, Italian Peninsula, and Balkan Peninsula.

In the third phase, Neanderthals remaining in the refuges are gradually replaced by modern humans. This phase typically lasts very long. This is because the refuges are permanently covered with forests and modern humans' innovative ability does not help them invade. Even worse, Mediterranean peninsulas are open only at their northern parts, where the temperature is relatively low and hence Neanderthals have higher viability. Thus those peninsulas function as effective refuges for Neanderthals, which is why it takes long for modern humans to invade them. I found that the refuge of the Iberian Peninsula is consistently stable and persistent compared to other refuges, so that modern humans tend to spend most of time in the third phase to break into this refuge. According to this result, it is highly likely that the last remains of Neanderthals are found in the Iberian Peninsula.

I also simulated a virtual world in which climate is stable. In this case, I found that the replacement may or may not occur, depending on the temperature. I.e., the replacement occurs if the northern boundary of the forest is located at relatively high latitude, but it may not occur if the boundary is located at low latitude. In the latter case, Neanderthals permanently survive in the Iberian Peninsula. In any case, modern humans finally spread into plains, but this requires far longer time than under variable climate. In addition, the spread of modern humans into plains does not strongly affect the population dynamics of Neanderthals, unlike under variable climate. Cultural diversity does not increase in any districts without climate variation. These results suggest that variable climate significantly affected the observed pattern of archaeological records.
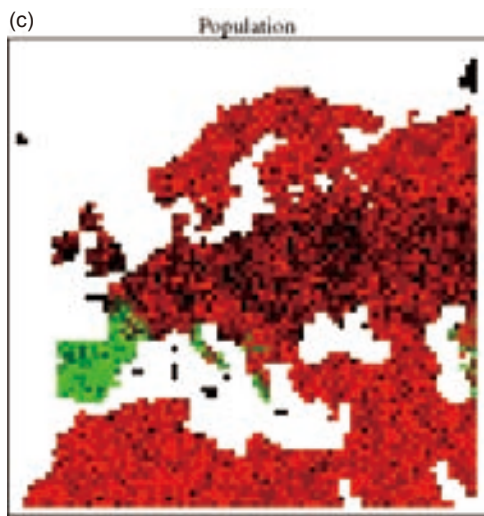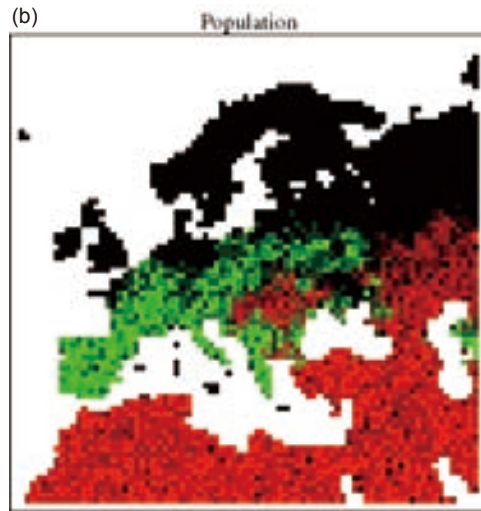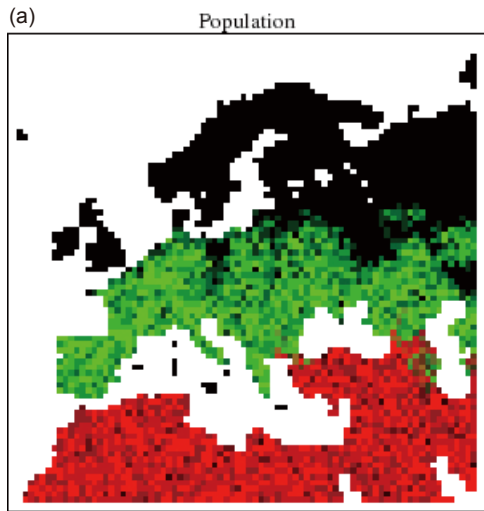
Figure 1. Simulated distributions of virtual Neanderthals (green) and modern humans (red) in (a) the first phase, (b) the second phase, and (c) the third phase. For the definitions of the three phases, see the text.
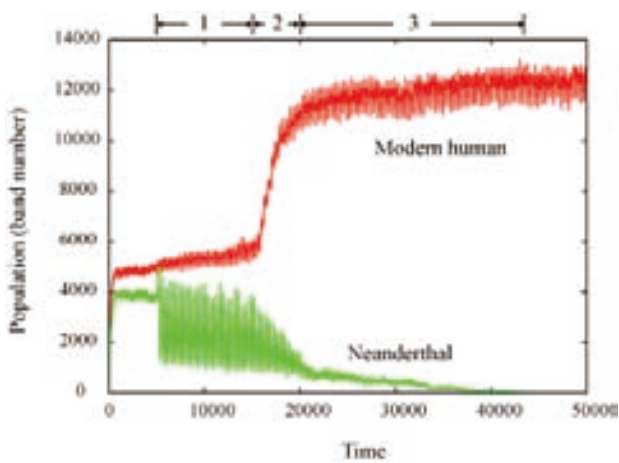
Figure 2. The population dynamics of virtual Neanderthals and modern humans. The numbers over the graph indicate the three phases (see the text).

A Mathematical Model of Cultural Interactions between Modern and Archaic Humans

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Our RNMH project is investigating the Paleolithic cultures around the world. Now we are recognizing that the pattern of cultural changes in each region had been various. In Africa, anatomically modern humans may have emerged around 200,000 years ago, and high level cultural traits appeared and disappeared iteratively in various regions before 90,000 years ago but cultural evolution speeded up and various new cultural traits appeared after that time. In Europe, modern humans invaded about 45,000 years ago and rapidly spread over every region except south Iberia. The artistic explosion of modern humans occurred soon after their invasion. That is, certain artistic behaviors of modern humans emerged first in Europe rather than Africa, and some researchers consider that interaction with Neanderthals had influenced these cultural innovations. In Asia, small scale invasion of modern humans may possibly have occurred before 74,000 years ago (inland route) and around 60,000 years ago (coastal route), and large scale invasion occurred about 40,000-50,000 years ago. Cultural change was not drastic but gradual in Siberia and East Asia.

When we study these "transitional" cultures, we have to consider the effects of interactions between modern and archaic humans. For example, when we study the culture of late Neanderthals, we consider the influence of modern human culture. However, no previous mathematical models of cultural evolution include cultural interactions. This is because previous models have a strong mathematical restriction for the probability distribution of cultural trait values each individual learns (Henrich,

2004; Kobayashi and Aoki, 2012). Therefore, I create a new model that has no restriction for the distribution to deal with cultural interactions.

Figure 1 describes the model. Cultural traits are expressed as real numbers, and every matured individual has one cultural trait (numbers in heads). A newborn (green individual) learns cultural traits from multiple individuals in their parental generation. He/She explores around socially learned cultural traits, and judges their utility following a criterion (red line) to adopt his/her mature cultural trait. He/She sometimes blends socially learned cultural traits to adopt the weighted sample mean, which reduces cultural variance in the population. We consider weak directional selection so that cultural traits with larger value have slightly larger utility. We obtain cultural evolutionary speed, which is defined as the generational change of mean cultural trait value in the population.

First, we consider cultural evolutionary speed of single population to compare the results with previous researches. Although previous researches argued that larger population size and larger number of acquaintances facilitate cultural evolution (Henrich, 2004; Kobayashi and Aoki, 2012), both have ignorable effect on cultural evolutionary speed in this model provided population size is large. This is because previous researches do not include blending effect, which is considered to be important in human cultural transmission (Boyd and Richerson, 1985). Moreover, even when a fraction of population is chosen as teachers, this effect on cultural evolutionary speed is also ignorable provided the number of teachers is large

and the mean cultural trait value of teachers is the same as that of the population, which is analogous to Aoki et al. (2011). Furthermore, even when a newborn tends to sample individuals with similar cultural trait, which may occur if the population is structured, this has no effect on cultural evolutionary speed. The width of exploring and the accuracy of judgment have positive effect on cultural evolution. That is, high individual learning abilities accelerate cultural evolutionary speed, which is analogous to Aoki et al. (2011) and Kobayashi and Aoki (2012).

Next, we study regional differences of the Paleolithic cultural change patterns from the model. Figure 2 shows the scenario of cultural evolution in Africa. At a certain time modern population with higher individual learning abilities appeared, and cultural level of this population evolved higher. However, cultural interaction with low ability archaic population with low level culture began as modern population expanded, which caused contamination of low level culture into modern population. This may have affected as a "rotten apple" so that cultural level decreased until the low level population went extinct. Such interaction may have occurred several times, which entailed iterative appearance and disappearance of high level culture in Africa. After almost all archaic humans in Africa went extinct, cultural evolution of modern humans speeded up.

Figure 3 shows the scenario of cultural evolution in Europe. Since modern humans could not invade Europe for a long time, their cultural level may have evolved high when they invaded Europe. Therefore, the difference of cultural level between Neanderthals and modern humans may have been large. Then, Neanderthal culture may have affected as a "negative exemplar" of how not to behave. Because of this effect, cultural level of European modern human population evolved higher than that of other modern human populations that did not interact with Neanderthals. In other words, cultural interaction with Neanderthals may have caused cultural explosion of European modern humans. Moreover, cultural interaction with modern humans may have entailed the evolution of high level culture

in Neanderthals.

Figure 4 shows the scenario of cultural evolution in Asia. First wave invasion of modern humans occurred when their cultural level was still low, so that cultural interaction with archaic humans may have affected as the rotten apple. When large scale invasion of modern humans with higher cultural level occurred, they may have interacted with descendants of first wave modern human population, so that the difference of cultural level may not have been large. Therefore, this interaction also affected as the rotten apple, so drastic cultural change never occurred. In other words, intermittent invasions of modern humans brought about the gradual cultural change in Asia.

Although these scenarios of cultural evolution in each region may be oversimplification, it is important to take cultural interactions with archaic humans into consideration when we study transitional cultures. This mathematical model suggests that cultural interaction can affect as both the rotten apple and the negative exemplar. I obtained the condition for cultural interaction to affect as the negative exemplar. I show that when modern humans experienced a small interaction with archaic humans with far lower level culture, this cultural interaction could affect as the negative exemplar. Although some researchers consider that the increase of the tension between Neanderthals and modern humans caused the artistic explosion in Europe, this model suggests that such reason was unnecessary provided Neanderthal culture was low level and the cultural interaction was small. If we consider that the increased tension caused the explosion, it is difficult to explain why the cultural explosion occurred in art, not in weapons or something that was useful for competing. Moreover since population size of Neanderthals may have been small compared with modern humans (Mellars and French, 2011), the tension may not have been strong and the interaction may have been small. Ignorable interbreeding between Neanderthals and modern humans in Europe from genetic evidence (Green et al., 2010) also suggests small interaction of both species. Before the invasion of modern

humans in Europe, Neanderthals had almost no artistic materials in their culture. Therefore, cultural difference in art was very large between Neanderthals and modern humans, so Neanderthals may have affected as the negative exemplar to cause the artistic explosion of modern humans.

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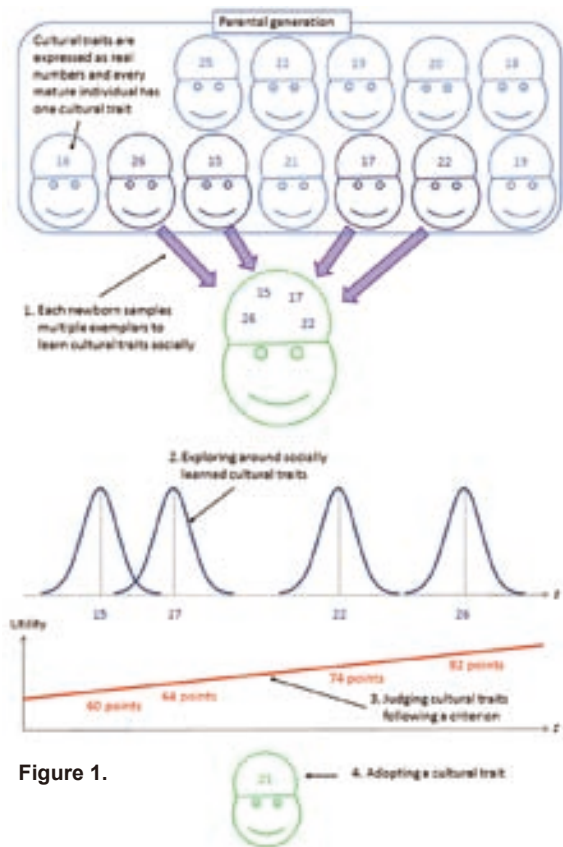
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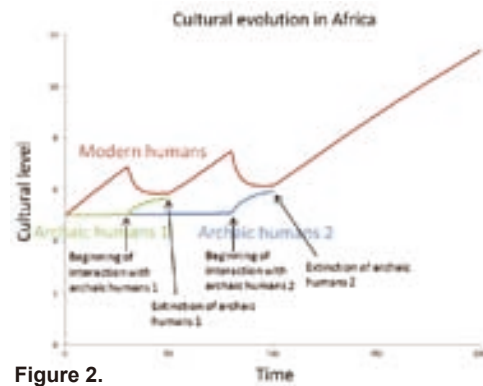
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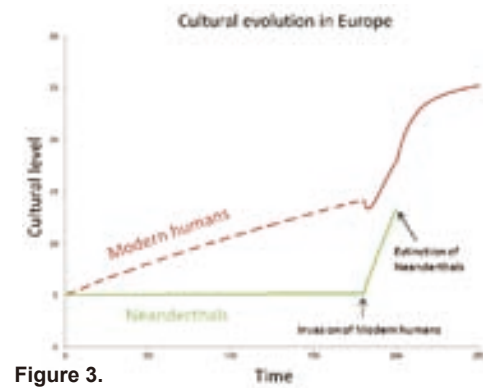
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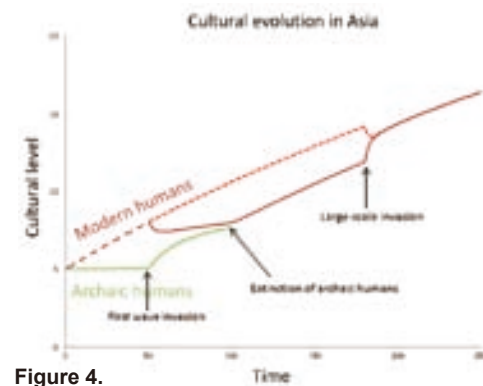
Figure 4.

An Attempt to Estimate the Functional Difference in Haplotypes between Archaic and Modern Humans

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Background

Progress of DNA sequencing technology and bioinformatics have brought us DNA sequences of archaic humans such as Neandertals and Denisovans. Because of post-mortem chemical alterations such as cytosine deamination, DNA sequences of the paleontological samples have been changed until the excavation. This is a limitation to estimate the functional differences between modern and archaic humans based on DNA sequences. To overcome this limitation, we discovered the haplotype sequences in modern human sequences that introgressed from archaic to modern humans in ancient time by determining linkage disequilibrium (LD) region using the database constructed by the 1000 genomes project.

Methods

We investigated the following five sequence elements (ancient haplotypes) that are known as unusual haplotypes because the recent African origin model cannot explained their divergence from other haplotypes in previous studies; an intergenic region on Xp11 (Xp11_hX), a region of MCPH1 on chromosome 8 (MCPH1_D), a region of RPM2P4 on chromosome X (RPM2P4_AB), a region around 44-th exon of DMD on chromosome X (dys44_B006), and a inverted region on chromosome 17 (17q21inv_H2). To extend the genomic region of ancient haplotype beyond that operationally determined in the previous studies, we estimated linkage disequilibrium (LD) regions that associate with ancient haplotype specific SNPs using the data of 1000 genomes project. Moreover, we annotated all SNPs on the extended genomic regions bearing SNPs that specific to ancient haplotypes (ancient haplotypes).

Results

We obtained SNPs that associate strongly ($r^2 \geq 0.8$) with SNPs specific to ancient haplotypes. The obtained SNPs specific to the ancient haplotypes contain three SNPs that are annotated to be in the region of transcription factor binding; CDP (CUX1, Figure 1) and OCT1 found in the intronic region of SHROOM4 gene located in the extend LD region of Xp11_hX, and CART1 that bind to intronic region of DMD (dys44_ B006). However, no non-synonymous SNPs were found. This suggests that the ancient haplotype specific SNPs affect regulation of the neighboring genes although the protein sequences of the neighboring genes are not changed.
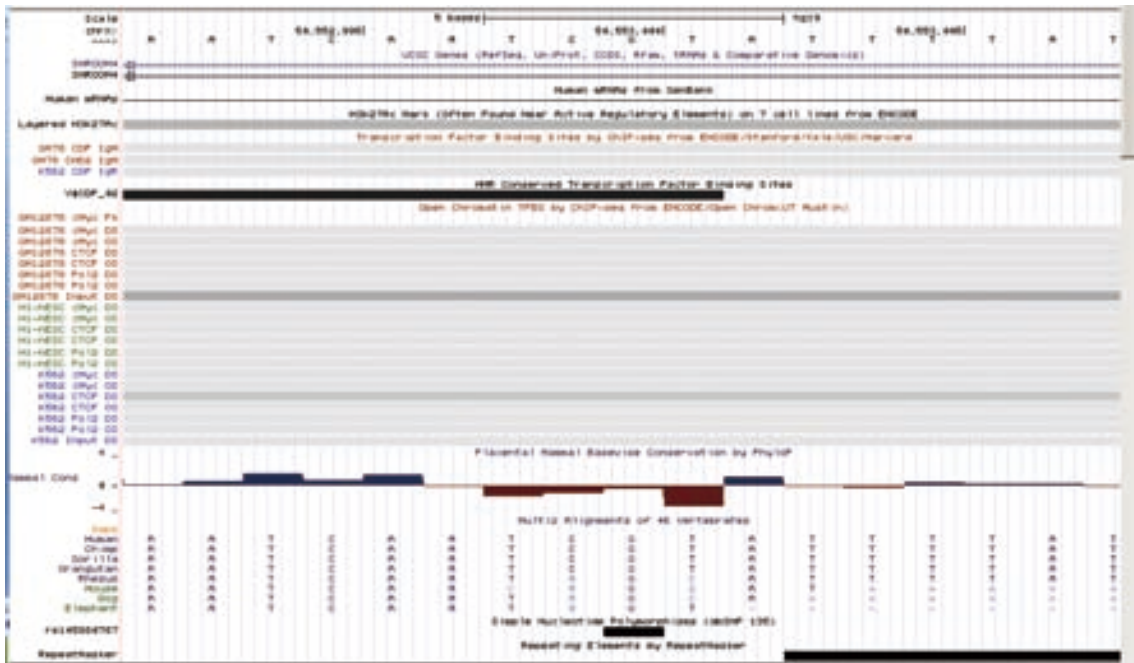
Figure 1. The ancient haplotype specific SNP (rs145880787) on the transcription factor (CDP) binding site.

The Down of Hierarchy: The Cognitive Ability of Archaic Hominins

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Despite sharing most of their genetic background, humans are remarkably different from other great apes. The most striking difference is related to cognitive skills acquired by *Homo sapiens*, and the fact that this knowledge had been accumulated and refined throughout its evolution as a species. Examples of these cognitive abilities are culture, language and tool manufacture. Within the genus *Homo*, these differences may not be as striking. Recently with the publication of the genomes of two archaic *Homo* specimens, new discoveries have contributed to a better understanding of the level of cognitive development of Neanderthals species (for instance speech ability). Humans and Neanderthals coexisted for a long while probably directly competing with each other in the same ecological niche. Over the decades, many assumptions have been made about the reasons for the replacement of Neanderthals by humans in Eurasia, many of them related to the cognitive differences between the two species. These assumptions are based on archaeological evidence pointing to a lower sophistication of the development and use of tools, as well as a less complex cultural and society in Neanderthals. In this study we sought to evaluate the variability in genes related to cognition in these two species of the genus *Homo* as an attempt to verify whether genetic differences in these could be associated to Neanderthal replacement. In order to identify genetic changes that are unique in humans we search for genes related directly with cognitive ability using Gene Ontology database

AmiGO (http://amigo.geneontology.org/cgi-bin/amigo/browse.cgi). Functional information and chromosomal gene localization details were obtained from GeneCards/GeneAlaCart database (http://www.genecards.org/). We performed all comparisons using modern humans genomes (NCBIBuild 36/hg18), chimpanzee (2.1/ pan Tro2 CGSC), Neanderthal and the Denisova specimen genomes (http://genome.ucsc.edu/cgibin/ hgBlat?org=human). All non-synonymous changes in cognitive genes which were different in modern humans and chimpanzees and that were available on Neanderthal and/or Denisova were recovered using the USCS Table Browser. The Grantham Score was then used to categorize all the corresponding amino acid changes into classes of chemical similarity. The sites were classified as conservative (Grantham score 0-50), moderately conservative (51-100), moderately radical (101-150) and radical (>150). The AmiGO search allowed the selection of 162 genes directly related to cognitive process. We found 94 non-synonymous substitutions in 52 genes, in which the derived allele was present in humans and the ancestral allele in chimp. Noteworthy 92.8% of Neanderthal positions have the same allele found in humans, 4.3% of the loci were heterozygote for ancestral and derived alleles and 2.9% of the loci showed new variants. In the Denisova specimen was recovered just 1 position with ancestral allele and 1 heterozygote locus with human and chimp substitution. From 94 substitutions, 46% were classified as conservative score, 38% as moderately

conservative, 11% as moderately radical and 1% as radical (PDCL and CHRNA4). The PDCL gene is a putative modulator of G protein involved in various neuronal signalizations, while CHRNA4 encodes a nicotinic acetylcholine receptor. Noteworthy that CHRNA4 presents one change in amino acid chain that differ from ancestral allele and *Homo sapiens* allele that surprisingly reached the highest Grantham Score position (159). In human, mutations in this gene are related to common disorders as Epilepsies Myoclonic, Attention-deficit hyperactivity disorder, mild mental retardation, psychiatric and neurological disturbs schizophrenia and others. It is possible to speculate whether this allele could be related to the cognitive differences between modern and archaic humans, notwithstanding the entire set of data does not point to mayor genomic differences between the species studied. Our results suggest that Humans, Neanderthals and Denisova specimens are virtually equal when the molecular aspects involved in the cognitive processes are considered. So if there were cognitive differences related to a less competitive Neanderthal behavior when compared to humans, these differences have left no mark on genetic background. Based on this, it seems more cautious to seek new directions to explain the replacement of Neanderthals by humans.

Using Numerical Models to Simulate Climate and Vegetation Changes during the Last Glacial Period

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During the Paleolithic Age, hunter-gatherers have had to adapt to changes in the natural environment as a result of geographic and climate changes. The last traces of the Neanderthals date back to about 25,000 years ago and, at some point, Neanderthals were replaced completely by Anatomically Modern Humans (AMH). However, the role of climate in the demise of the Neanderthals is still a subject of debate. One hypothesis put forward is that the extinction of the Neanderthals resulted from their inability to adapt to extreme climatic changes during oxygen isotope stage 3 (OIS-3) (Stewart, 2005). The climate during OIS-3, which spanned roughly 65,000 to 25,000 years ago, was characterized by abrupt changes known as Dansgaard-Oeschger (D-O) events (Dansgaard et al, 1993) which brought about rapid warming episodes, followed by cooling over a longer period (Figure 1). It has been suggested that these events, which appear to occur around every 1500 years, were associated with the changing state of the Atlantic thermohaline circulation, weak during the cool stadials but stronger during the mild interstadials. Preceding some of these D-O events of the last glacial period were Heinrich events (Heinrich, 1988) which coincided with the break-up of ice shelves in the northern hemisphere and the release of large amounts of freshwater and ice rafted debris into the North Atlantic Ocean.

Climate modellers have used numerical models to reconstruct the climates of OIS-3 (e.g. Sepulchre et al, 2007). Paleoclimate data such as pollen, tree rings, ocean sediments and ice cores have given us a greater insight into the climate of the past and the way in which it has shaped the natural environment through changes in vegetation. In addition, they can complement numerical models as comparisons can increase our confidence in model simulations while simulations themselves may give us information in regions where data are sparse. The combination of numerical climate models and paleoclimate data thus provides a very useful tool.

In our current work, we use numerical climate models and incorporate proxy data to build a clearer picture of the climate during the 120,000 years so that we can better understand the its effect and that of vegetation changes on the distribution of Neanderthal and AMH population. We
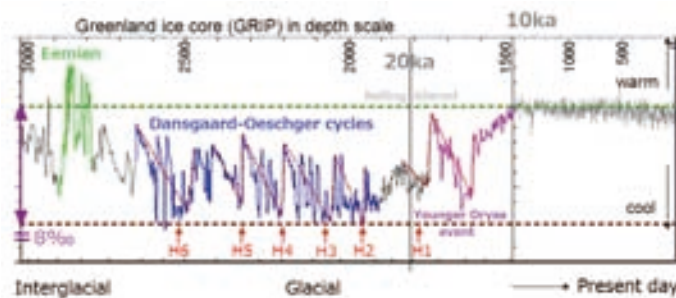
Figure 1. Dansgaard-Oeschger cycles (blue) and Heinrich events (red) as inferred from Greenland ice core data. The vertical axis represents the isotope ratio δ¹⁸O, a measure of the temperature which increases upward.

have used a mid-resolution version of a coupled atmosphere-ocean general circulation model (AOGCM), called the Model for Interdisciplinary Research on Climate (MIROC), developed at the institutes CCSR/NIES/FRCGC in Japan (K-1 Model Developers, 2004). For time slice experiments of the last glacial-interglacial cycle, conditions need to be specified within the model. These conditions are the orbital forcing, greenhouse gas concentration and ice sheet extent. To mimic the effects of the release of freshwater into the North Atlantic Ocean, some AOGCM simulations include "freshwater hosing" whereby freshwater is artificially discharged over the northern North Atlantic (Manabe and Stouffer, 1997).

Results from these time slice experiments are applied to a dynamic global vegetation model (DGVM), Lund-Potsdam-Jena DGVM (Sitch et al, 2003), which is run offline to study the vegetation response to various climate scenarios (Figure 2). Climatological monthly mean values of precipitation and surface air temperature are calculated over a suitable period after the climate has reached an equilibrium state in the AOGCM. These monthly values are fed into the DVGM which is run with atmospheric CO_2 levels specified as before. The output data are vegetation types represented by 10 plant functional types.

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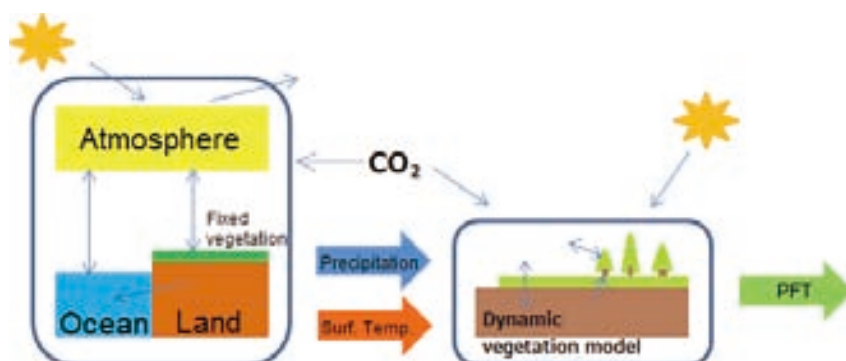
Figure 2. Simple schematic diagram of a coupled AOGCM and dynamic vegetation model.

Late Middle Palaeolithic (OIS 4/3) Neanderthal Prey Exploitation and Land Use at Dederiyeh Cave, Syria, Based on Multiple Isotopic Analyses of Intra-Tooth Enamel and Mortality Profiles of Wild Goat, Red Deer, and Gazelle

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Our closest cousins on the human evolutionary line, the Neanderthals, survived for several hundreds of thousands of years through drastic climatic modulations that also brought with it complex ecological, biogeographic, and subsistence-settlement challenges. However, much has been written about their extinction, and thus apparent failure to survive, while little has been stated about the obvious ecological and social resilience they demonstrated through millennia of expansion throughout Europe and the Levant. The question of why they became extinct still remains.

One explanation may come from a body of concepts defined within socio-ecological resilience theory that attempts to explain changes in adaptive systems that are "transforming". Resilience theory is based on an adaptive cycle nested in a space-time hierarchy involving stabilizing and destabilizing effects that can cause small-scale transformations to explode into larger-sale crises (panarchy). In otherwords, unlike anatomically modern humans, in times of socio-ecological stress, some Neanderthal groups may have lacked technological, social, and subsistence flexibility/knowledge in a rapidly changing adaptive system and were incapable of reorganization strategies required during dynamic changes. On a population scale this may have been linked to an increase in calories that would have permitted modern humans to increase fecundity and, thus, survivorship.

Stable isotope analysis and mortality profiles of prey species may provide palaeoecological support for extinction and replacement hypotheses.

The ecologist Daniel Simberloff has referred to the final members of a species on the verge of extinction as "the living dead" since they appear to be healthy and active, yet lack key facets for the species to maintain itself—to be resilient, that involves social transmission, genetic drift, lack of breeding females, low recruitment (births), increasing deaths, and negative immigration from dwindling source areas. One interpretation may be that Neanderthals could not recoup losses due to an inability to "reorganize" themselves after dynamic natural and social changes. They were incapable of "releasing" their economic and genetic stress to reorganize for an "exploitation" phase, that a new, more adaptable group appearing from out of Africa could.

This research presents the first isotopic results and mortality profiles of key herbivore prey from a Neanderthal site in the northern Levant, that of Dederiyeh Cave in northwest Syria. Serial sampling from the early enamel forming occlusal surface of the crown, to the later enamel-cementum junction was conducted on a small sample of wild goat (*Capra* aegagrus cf.) and red deer (*Cervus* elaphus). Combined results of carbon (δ^{13}C) and oxygen (δ^{18}O), and oxygen and strontium (^{87}Sr/^{86}Sr) isotopes over the 1-2.5 year period of molar enamel formation from wild goat yield little variation reflecting local, and restricted range habitat. This has implications for the land use practices of Neanderthals who occupied the region around the cave. It suggests prior knowledge of the presence of key herbivore

prey and seasonal occurrences, and thus, potentially an element of complex planning and decision making regarding the timing and scheduling of logistical or residential hunting practices. Ethnographic evidence of wild caprid and ovid hunting sometimes involves medium duration (a few days to one week) logistical forays involving several hunters interacting communally. An analogical argument from these examples can be extrapolated to hypothesize that late Levantine Neanderthals required similar approaches to that seen ethnographically.

Age profiles, based on time-averaged dental wear patterns and metrics, for wild goat, red deer, and gazelle closely reflect that of southern Neanderthal samples from Kebara cave in Israel, from a similar period across the OIS4/3 (70,000-40,000 kya) transition. Wild goat confidence intervals on a triangular (or ternary) graph fall within an ambush hunting strategy while red deer indicate higher prime-age deaths, and gazelle trend toward a higher juvenile-subadult mortality pattern. It also suggests a consistency in hunting patterns and prey herbivores that may have been learned through transmission from groups close by or within a larger biogeographic regional boundary. These profiles are preliminary pending a more comprehensive investigation incorporating other aging schemes using long bone fusion and dental annuli. While the isotopic results are sound and provide a stronger inferential base upon which to interpret climatic, ecological, and biogeographic explanations of Neanderthal herbivore prey and Neanderthal subsistence and land use at the pivotal OIS4/3 transition, they must still be considered in concert with potential sources of error. However, there is adequate explanatory value in this pilot study that justifies preliminary inferences about herbivore physiology, palaeoclimate, and Neanderthal subsistence, as well as the potential for deeper critical analysis with an augmentation of additional data in future investigations.

How Can We Apply Ecological Niche Models to Palaeoanthropological Research?

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Ecological niche modelling is a computer-based method to simulate species' geographical range (or ecological niche) expansion or contraction based on either real or simulated environmental conditions. It is also applicable to palaeoanthropology and archaeology as eco-cultural niche modelling (ECNM), because in prehistory human behaviours were largely influenced by the environmental impact [1]. Based on this assumption, we apply ECNM to the spatio-temporal reconstruction of the replacement of Neanderthals by anatomically modern humans (AMHs) in response to climate change. For the practical application of ECNM, pre- and post-processing treatments to control the data quality and outputs are necessary. This paper introduces techniques for preparing high resolution palaeoclimate data and palaeovegetation zoning in the pre-processing and for model integration in the post-processing. Preliminary experiments are carried out to the eco-cultural niche distribution of the Magdalenian culture in Western Europe during the Last Glacial Maximum (LGM).

High resolution palaeoclimate data

There is a difference in analytical scale between the palaeoclimatic and palaeogeographic data. For instance, the MIROC 3.2.2 atmosphere-ocean general circulation model in the PMIP 2 protocol [2] has data points in every 2 arc-degrees. In contrast, the resolution of the GTOPO-1 digital elevation model (DEM) is 1 arc-minute (or 0.01667 arc-degrees). It is important for ECNM software packages to match the pixel size of raster-based environmental data prior to analysis. Therefore, it is necessary to increase the resolution of the climatic data. For this purpose, we employed the 30-arc-second (or 0.008335 arc-degrees) climate model of the present day, published by the WorldClim project (http://www.worldclim.org).

The procedure of resolution increase is simple. First, the difference between the value of the present day and that of 21 ka was calculated for each data point of the MIROC. For example, the difference in annual precipitation was calculated as:

$$\Delta P = P_{21k} - P_{0k} \qquad (1)$$

where ΔP is the difference, and P_{21k} and P_{0k} are the precipitation at 21 ka and present (0 ka), respectively. Then, the data points of ΔP were interpolated by a spline algorithm to create a raster surface in 1 arc-minute pixel resolution. Similarly, null cells (or water surfaces) of the WorldClim data were filled by spline interpolation and downsized to 1 arc-minute pixel. Finally, the interpolated WorldClim data were converted to the LGM data by subtracting the difference ΔP.

$$P_{21k} = P_{wc\_sp} - \Delta P \qquad (2)$$

where [Pwc_sp] is spatial matrix of the interpolated precipitation of the WorldClim. The similar method was applied to create the high resolution raster data of the mean annual, warmest month (August), and the coldest month (February) temperatures.

Palaeovegetation zoning

Figure 1 shows an experimental prediction of the geographical extent of the Magdalenian niche at 21.2 ka. The left subfigure is the prediction

with the biome (biome model), while the right subfigure is the prediction without the biome (non-biome model). Macroscopically, the two results are similar, particular in that high probabilities of site occurrence are predicted in the southern part of France, Belgium, the northern half of Switzerland, and the Cantabrian coast of northern Spain. However, there are some differences when we look at details: the high probability areas of the non-biome model (right) in the west coast of the Iberian Peninsula, the Italian Peninsula, and the northwestern part of the Balkan Peninsula are missing in the biome model (left). Furthermore, in the biome model, the boundary of high and low probability zones tends to be sharp in some parts, which is caused by the input of the biome as a categorical value. This fact primarily indicates that a revision of the category and geospatial zoning of biome and palaeovegetation, with reference to the plant functional type reconstructed from pollen and other palaeobotanical records, is essential to a better application of ECNM to RNMH research. In order to reduce the edge effect, each categorical type was separated and converted to a continuous value (0 … 1) with fuzzy marginal buffers. Then, the sum of the values at each cell was standardised to 1. This treatment contributes to visualising the boundaries of biome in a more naturalistic manner.

Model selection and integration

Among ecological niche models, GARP (genetic algorithm for rule-set production) [3] and MaxEnt (maximum entropy model) [4] are commonly applied in ECNM. Although both models employ the similar inputs of location of palaeoanthropological sites and the environmental dataset, these two algorithms tend to yield strikingly different results from the same dataset and similar parameter settings. In general, the geographical extents of the niche predicted by MaxEnt tend to be narrower and more biased than those predicted by GARP [5]. This tendency has also been observed in our comparative experiments. We suggest calculating geometric mean of the standardised GARP and MaxEnt models in order to highlight the geographical ranges in which both models predict high probability of species' presence. The contribution of each environmental variable to the output model is also important to understand what environmental factors are influential to human behaviour, which might have different responses to climate change in comparison to other biological species as a manifestation of emerging culture.

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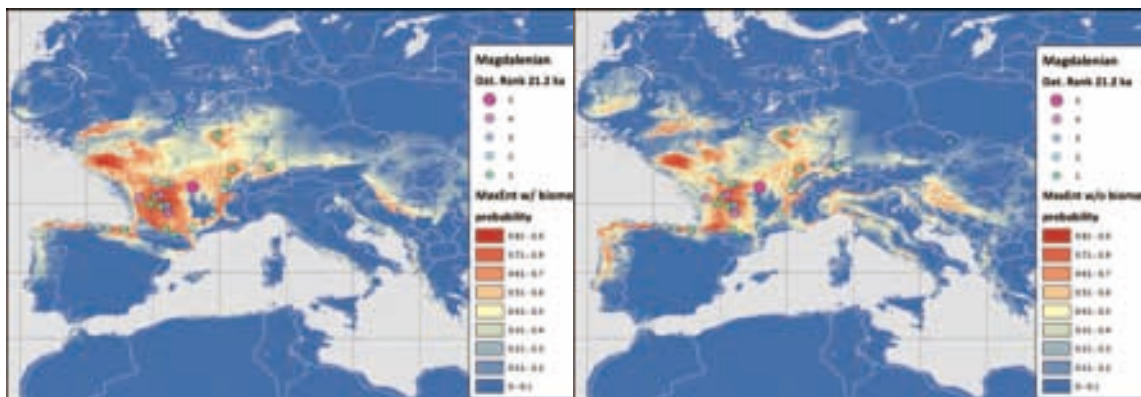
Figure 1. ECNM of Magdalenian niche range from the biome model (left) and non-biome model (right).
See also the paper by Omori and Yoneda in this volume for qualification of radiocarbon date reliability (Dat. Rank).

Bibliographic Database for "Replacement of Neanderthals by Modern Humans"

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Creation of bibliographic data

We have been constructing a bibliographic database for "Replacement of Neanderthals by Modern Humans" covering reports on relics and remains of relevance to the Replacement of Neanderthals by Modern Humans project. By the end of 2011, we had successfully digitized a total of 2,713 pieces of bibliographic materials, including full-text conversion of 60,613 pages.

Subsequently, we created metadata for each of these bibliographical materials, adding remain name, location, era, keywords and other pertinent facts, as well as standard bibliographic information such as title, author, publication year, journal name, volume number, and pages. We initially created the catalog data in Excel files and, after importing them into the bibliographic search system, edited the data directly from Web browsers.

Bibliographic search system

We constructed a dedicated bibliographic search system for the purpose of searching for and browsing bibliographical materials utilizing the aforementioned digitized literature metadata. This system stores the bibliographic data and is composed of a search environment for users (front end) and a data editing environment (back end).

The front end allows searching by free text, author, publisher, and publication year. For authors, in particular, the system is equipped with a so-called suggest function, which makes an indexed author list from the database and displays likely author candidates in response to inputs from users.

In addition, search results are displayed in order of author names. If there are multiple author names matching the search, the results are sorted by the first author name and displayed in the ascending order of the number of authors and then the publication year. The list of search results shows bibliographic information as well as links to full-text PDF files (Figure 1). Users can click on the links to immediately display the full-text PDF files of the relevant literature.

The back end has an interface that allows editing contents of the database. Users with editing rights are able to use internet browsers to list and edit data. We use this back end to correct typographical errors, characters omitted in the text conversion process etc., and add related information. Since it allows searching for target literature and working on the data while displaying full-text PDF files of

Figure 1. Search screen of the "Replacement of Neanderthals by Modern Humans" bibliographic database.

the target literature, we are able to edit the data more efficiently than by working with Excel files, which we did at first.

Coordination with external databases using associative technology

Creating the bibliographical material database opened up the possibility of linking with external databases. We thus made use of the Associative Retrieval System "IMAGINE" Book Search to build a service for looking up items pertinent to target literature from existing fossil databases. Moreover, taking advantage of the literature browsing system "eReading" (Figure 2), we constructed a service that allows looking up item names in fossil databases and encyclopedias while browsing literature PDF files. This service utilizes functionality from the "Ebiki" system that allows attaching annotations to images.

Coordination with these systems allows us to directly add external bibliographic data to our bibliographic database. To further facilitate the integration, we employed a data format that is relatively easy to handle in our bibliographic database and allows partial update of the data simply by specifying an ID for the data.

Utilization of the bibliographic database and effort toward construction of remains database

Our purposes for constructing the bibliographic

Figure 2. Linkage between body text and pertinent items via "eReading".

database are not limited to searching for literature itself. We have another purpose as well; full-text data of bibliographic materials contain large volumes of descriptions of facts and figures, and we want to be able to browse such information systematically as well. In case of remains in particular, the actual sites may be lost during archaeological excavation, and descriptions of remains in bibliographic materials thus carry significant weight.

Towards this end, as part of our study of applications of the bibliographic database, we are working on design and development of systems used to organize and deliver information focusing on remains. Specifically, we created test data and developed a prototype database of remains, by referring to the recent report on the Dederiyeh Cave (Akazawa and Muhesen eds. 2003). In the development, we focused on monograph figures and photos in the paper and attempted to design the system to extract and format as much information on remains as possible from the bibliographic materials. For example, in order to directly link captions to figures, we made use of the aforementioned functionality for attaching annotations to images and incorporated latitude/longitude data of shooting locations, shooting directions and other elements into photos. We aim to upgrade and improve the delivery environment as part of our future development of the system and achieve a service environment that allows browsing minute information on remains.

Reference

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  2003 Neanderthal Burials - Excavations of the Dederiyeh Cave, Afrin, Syria. Auckland : KW Publications Ltd.

Plant Creating a Common Chronology for Levant Pollen Records Based on Ice Core Synchronization

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The early portion of the last glaciation is beyond the range of reliable radiocarbon dating. This is problematic for assigning ages to an important period in human history that includes the migration of modern humans out of Africa and their eventual replacement of Neanderthals. In addition to the assignment of absolute age, this also complicates understanding the relative deposition timing of stratigraphic layers from distant sites.

An alternate dating method is the comparison of environmental proxy records, obtained from the area of interest, to the Greenland ice cores air temperature records. Multiple large-amplitude, abrupt warmings, commonly known as Dansgaard-Oeschger (D-O) Events, punctuated the last glaciation. A large body of work indicates that these interstadial events are expressed as contemporaneous environmental fluctuations over a wide spatial area, centered on the North Atlantic Ocean and adjacent continental regions, with far-reaching connections to more distal areas.

North Atlantic sea surface temperature proxy records obtained from marine sediment cores often exhibit a warming and cooling pattern comparable to Greenland. Similarly, in continental regions, pollen-based environmental reconstructions indicate the return of relatively warm and humid conditions during Greenland interstadials. Within the range and resolution of radiocarbon dating, these fluctuations occur simultaneously with Greenland air temperature changes.

The age of the ice in Greenland cores may be determined though the summing of annually deposited snow layers with a similar accuracy as radiocarbon dating. For example at 50,000 years, the Maximum Counting Error of the North GRIP (NGRIP) ice core is approximately ± 1,000 years (1σ), which is roughly comparable to the uncertainty in the latest radiocarbon calibration (IntCal09) prior to the addition of measurement error. Therefore, the combination of high precipitation rates in Greenland with the large spatial extent of the synchronous temperature changes provides a powerful tool for assigning ages that would otherwise be unknown.

However, there have been significant revisions to the Greenland ice core chronology over the past 15 years, and many of the published age models of both marine and lacustrine sediment cores are not compatible. The largest offsets, up to 4,000 years, are between the early-glacial sections of the GISP2 and NGRIP ice cores, which is the exact interval in which radiocarbon is no longer of use. Up until 2005, the Meese-Sowers 1994 (MS94) layer-counted chronology for the GISP2 ice core was the most widely used correlation target.

Since that time, very high density sampling of the newer, virtually complete NGRIP ice core indicates that GISP2 likely suffers from excessive layer thinning, and the NGRIP GICC05 layer-counted chronology, extended with the ss09sea flow model, has subsequently replaced GISP2 as the preferred chronology. Comparing older, GISP2-aged data with newly published data requires updating the former to the GICC05

model-extended chronology.

Here we present an automated mathematical function for doing so using either the Matlab or Octave (free, open source version of Matlab) high-level numerical computational languages. The function is based on synchronization of the ice cores and allows for specifying the age of the oldest radiocarbon data as a starting point for converting any input series from the MS94 to the GICC05-extended chronology. The output ages are relative to the number of calendar years before AD 2000 (i.e., kiloyears b2k). Dates outside of the GISP2-to-NGRIP conversion range are not adjusted except for adjust to the b2k scale. This will facilitate immediate comparison of older and newer data and will be the basis of a consistent chronology for pollen records obtained from the Levant region.

Population Dynamics and Spatial Distribution Inferred from Radiocarbon Meta Analysis

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Meta analysis of radiocarbon database provides information about population dynamics independently of archaeological and anthropological approaches. Assuming the datable sample, such as charcoal, human skeleton and animal bone, corresponds to evidence of human activity, the number of reported radiocarbon dates can be interpreted as qualitative population dynamics. Several studies have been reported on the radiocarbon meta analysis for the Upper Paleolithic in Europe, and the radiocarbon-based chronology as well as its frequency distribution have been discussed to understand the replacement.

In this study, we evaluate the published radiocarbon dates and reconstruct the chronology of the Upper Paleolithic in Levant and Europe. Radiocarbon dates and archaeological information were taken from our own chronological database "NeandatDB" and PACEA geo-referenced radiocarbon database (d'Errico et al., 2011). In addition we attempt to estimate population dynamics and its special distribution.

Generally almost all radiometric databases include a number of problematic dates from the viewpoint of technical confidence in the measurement, adequacy of sample material and so on. Most of them are reported during an early period of radiocarbon research. Even though some unreliable dates incorporated in database, the meta analysis would be able to exhibit rough outline of the chronology if mass data was used. However, when comparing the obtained chronology and abrupt paleoclimate events, more high temporal

resolution is required.

The reliability assessment of radiocarbon dates follows a decision tree, which is constructed from purely technical standpoint. For the decision tree, we set up mainly four evaluation criteria: oldness of radiocarbon age, margin of 1σ error, sample material type and technical comment on the publication. The data reliability is rated on a scale of one to four. The reliability score 1 is ruled unfit to apply the meta analysis, and rejected in this study.

For radiocarbon age calibration and meta analysis, we use OxCal 4.1 and 4.2 beta program (Bronk Ramsey, 2009 and 2012). All of the accepted data (score 2 to 4) was calibrated by Intcal09 calibration curve (Reimer et al., 2009), and then carried out radiocarbon data analysis. The calibrated dates were classified into lithic industries as population groups, and the temporal frequency distributions were calculated from the data groups using radiocarbon Bayesian analysis.

Figure 1 illustrates the temporal distribution of Mousterian, Aurignacian and Gravetian lithic industries throughout the European region. Patterns of the distributions were altered by the assessment evaluation, especially in later period of each industry. In the Mousterian industry, which is Neanderthals lithic culture, there are no substantial fluctuations in the duration, and the frequency has reduced gradually over time. On the other hand, there are large changes in the distributions of the Aurignacian and Gravetian as Modern human cultural groups around 35,000 BP and 30,000 BP.

The spatial distribution from the evaluated data is

shown in Figure 2. Although the distribution of the Neanderthals has been contracting over time, the distribution area of Modern humans seems to no change from the 40,000 BP despite some fluctuations in the temporal distribution. In this paper, we discuss these time and spatial distributions in detail, and estimate the population dynamics based on the result.
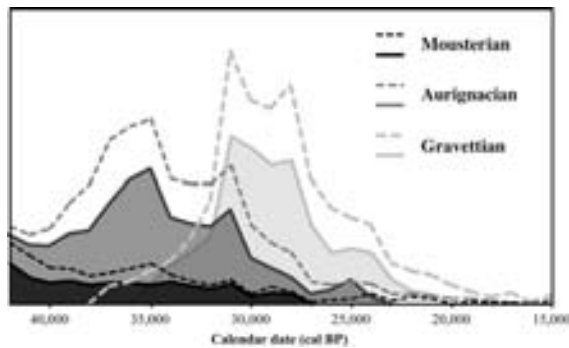
Figure 1. Temporal frequency distributions of the Mousterian, Aurignacian and Gravettian lithic industry. Each solid and dashed line was derived from only the acceptable radiocarbon data and all the data in the database respectively.
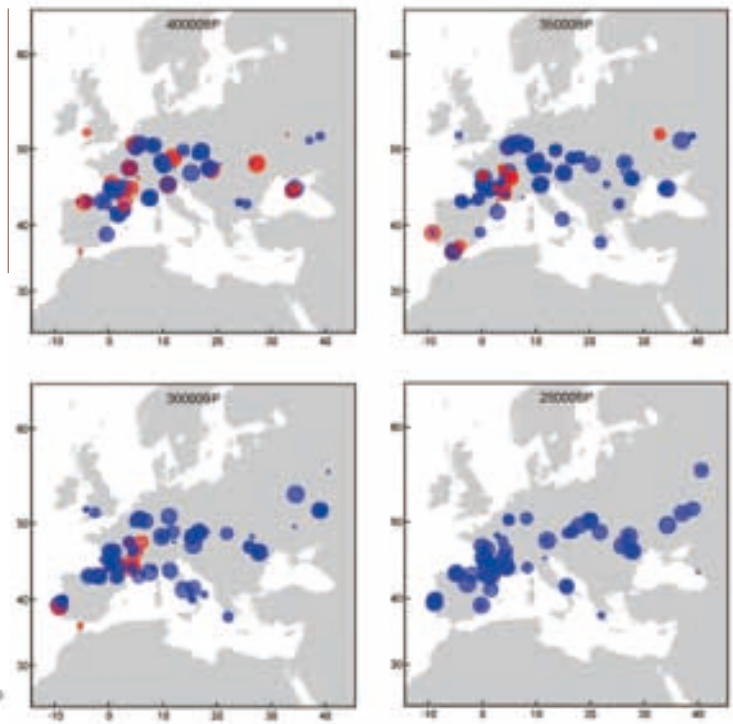
Figure 2. Special distribution of Neanderthal and modern human groups based on the evaluated radiocarbon data. The size of plotted circle represents the probability of the existence of population groups. Red and blue circle belongs to the Mousterian industry as Neanderthals and the Aurignacian and Gravettian industry as Modern humans respectively.

PaleoGeo: A Web GIS for Distributing Information from Paleoenvironmental Literature

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There is a growing interest in the paleoenvironment, and the number of relevant research papers has been growing rapidly. Paleoenvironmental studies cover various fields such as paleohydrology, geomorphology, paleooceanology, paleobiology, paleoclimatology, and chronology. It is hard to collect and compile these enormous data by an individual researcher. For the multidisciplinary project, "Replacement of Neanderthals by Modern Humans (hereafter RNMH)", we have been compiling portal data by using a web-based geographical information system (Web-GIS). We call this system "PaleoGeo". It helps an individual researcher to search paleoenvironmental information efficiently.

The PHEIMS (Paleo-Hydrology and Environment Internet Map Server), a precursor of the PaleoGeo, was developed in the late 1990s by one of the co-authors (T. O.), using ESRI ArcView IMS as a main server software package. It contained information from papers in international journals of earth and Quaternary sciences published during the mid-1990s to 2002. It was viewed up to 3,000 times annually; however, its updating ceased because of the end of the relevant project.

Figure 1. Interface of the PaleoGeo. Yellow pins show sites with information such as location (latitude and longitude), bibliographic data, keywords, and period. Each record is linked to the publisher's abstract website using a permanent link (DOI).

The PaleoGeo is being developed to revive and update the PHEIMS. We improved the user interface and data quantity (papers up to year 2011). The new system uses ESRI ArcGIS Server 10 and to reduce redundancy of the data, a relational database management system (RDBMS) is applied.

The data consist of the journal name, information about each paper (authors, title, volume, year, and page numbers), site location (country name, longitude, and latitude), theme, subtheme, keywords, DOI (Digital Object Identifier), and period (era). DOI enables users to see publisher's abstract pages in one click. Bibliographic information is also available at some existing web-based search engines such as the ISI Web of knowledge. However, location data are indispensable in paleoenvironmental studies. The PaleoGeo shows information with a map (Figure 1), which is the most distinguishable advantage of this database system.

We have collected information from almost three thousand articles of 13 journals regarding paleoenvironmental research (i.e., Boreas, Catena, Climatic Change, Earth Surface Processes and Landforms, Geomorphology, Journal of Quaternary Science, Palaeogeography, Palaeoclimatology, and Palaeoecology, Quaternary International, Quaternary Research, Quaternary Science Reviews, The Holocene, and The Journal of Geology). The articles were classified into six themes (paleohydrology, earth surface processes and materials, paleooceanology, paleobiology, palaeoclimatology, and chronology) and 19 subthemes (hydrology, flood, fluvial, glacier, fluvial/glacier, sedimentology, soil, slope process, periglacial, peat land, eolian, sea-level, biology, vegetation, zoology, vegetation/zoology, archaeology, climate, atmosphere, and chronology). The original data can be viewed as a search result (Figure 2). Until now, information of 6,881 sites has been collected and the number is being increased.

Although the PaleoGeo seems to be a useful tool, it has room for improvement; for example, expanding a window showing search results, and improving the map print function. We will fix such problems as soon as possible. In the future, this database system will be connected to the holistic bibliography catalog of the National Institute of Information (NII), Japan. This will be another way for the effective use of the system.

Figure 2. Part of original data after a search query.

Statistical Interpolation of Missing Parts in Fossil Crania

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During fossilization, crania are often fractured and all the component fragments are rarely recovered. To establish anatomically accurate interpolation of missing parts of fossil crania is of crucial importance for correct estimation of brain morphology based on cranial shape information. In the present study, therefore, we attempted to establish a method to statistically interpolate missing coordinates of crania based on reference database of cranial morphology.

To construct reference database of human cranial shape, we used a total of 22 crania (9 female and 13 male crania) from the modern Japanese population housed at Kyoto University. Each cranium was scanned using a CT scanner and the 3D surface model of the cranium was generated. On the surface of each cranium, 17 anatomical landmarks were digitized. Furthermore, the midsagittal, superior nuchal, and tempral curves were approximated using a seventh-order Bezier curve and equally spaced points along each of the curves were also defined as landmarks. To capture the morphology of the entire cranial vault, 39 shortest path connecting pairs of landmarks were calculated and equally spaced points along each of the paths were also defined as landmarks. Therefore, a total of 110 landmarks were acquired for each specimen to describe the biological shape. The landmark coordinates were then normalized by the centroid size and registered using the Generalized Procrustes Analysis.

Based on a sample of complete specimens as reference data, multivariate regressions are calculated with the missing coordinates as dependent variables and other remaining coordinates as independent variables. Let $\Delta\mathbf{p}_i$ (i=1..N) be the (3×1) position vector of the ith missing landmark from the consensus cranium and $\Delta\mathbf{x}$ be the (3(110-N)×1) vector representing the deviations of the remaining landmark coordinates from the consensus (N is the number of the missing coordinates). The regression equations can be written as:

$$\Delta\mathbf{p}_i = \mathbf{A}_i \begin{bmatrix} \Delta\mathbf{x} \\ 1 \end{bmatrix} \tag{1}$$

where $\mathbf{A}_i$ is the (3×3(110-N)+1) matrix of regression coefficients for $\Delta\mathbf{p}_i$. To solve for $\mathbf{A}_i$, we exploited correspondence between $\Delta\mathbf{p}_i$ and $\Delta\mathbf{x}$ in the complete specimens. Specifically we solved the following simultaneous equations for $\mathbf{A}_i$.

$$\begin{bmatrix} \Delta\mathbf{p}_{i,1} & \Delta\mathbf{p}_{i,2} & \cdots & \Delta\mathbf{p}_{i,S} \end{bmatrix} - \mathbf{A}_i \begin{bmatrix} \Delta\mathbf{x}_1 & \Delta\mathbf{x}_2 & \cdots & \Delta\mathbf{x}_S \\ 1 & 1 & \cdots & 1 \end{bmatrix} = \mathbf{0} \tag{2}$$

where $\Delta\mathbf{p}_i$,j and $\Delta\mathbf{x}_j$ (j=1..S) be the $\Delta\mathbf{p}_i$ and $\Delta\mathbf{x}$ of the jth complete specimen, respectively, and S is the number of the reference complete specimen. As the number of equation is less than the number of unknown quantity, the solution is underspecified. Hence we used the Moore-Penrose pseudo-inverse matrix to obtain the solution. In order to examine the efficacy of the proposed interpolation method, we virtually created crania with missing portion. Figure 1A shows the virtually generated crania with 5 (top row) and 20 (bottom row) missing landmarks, respectively. The missing landmarks in the crania were then estimated by using Equation (1) and the estimated coordinates of the missing landmarks were compared with their true values.

Figure 1B compares the estimated positions of the missing landmarks with those of the original cranium. Here the neurocranial shape is represented by the wireframe connecting the landmarks. As illustrated, the estimated positions of the missing landmarks are located reasonably close to the corresponding landmarks on the original cranium. The mean prediction errors (± standard deviation) were 2.6 ± 1.6 mm and 2.9 ± 2.3 mm for the crania with small and large missing portions, respectively. Although introduction of adequate constraints seem necessary since solving Equation (2) is an ill-posed problem, the present interpolation framework may contribute to precise estimation of missing parts in fossil crania.
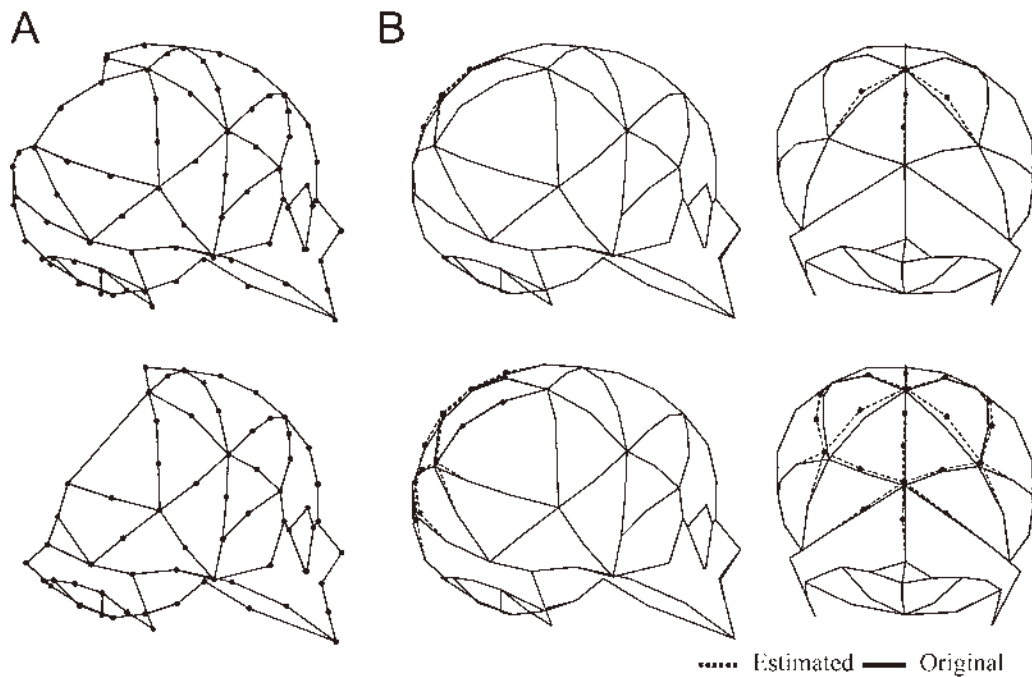
Figure 1. (A) Virtually generated crania with missing portion. (B) Comparisons of the estimated positions of the missing landmarks with those of the original cranium.

CT Image Segmentation Using FEM with Optimized Boundary Condition

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We propose a CT image segmentation method using structural analysis. Motivation of our research is from the area of fossil reconstruction to decompose assembled fossil of skeletons and crania to their fragments. X-ray CT is used to scan an assembly then its image is manually segmented into pieces of the bones. Considering the number of fragments involved, it is desirable to make this segmentation procedure automatic. A problem specific to this segmentation is to separate fragments where their gap are not necessarily clear. Despite the numerous image segmentation methods, none of them matches our objectives.

Accordingly, we previously proposed a method to segment CT images using structural analysis. The technique is based on the assumption that the interference area (joint) between components (bones) is structurally weak. We compute strain, which tends to be large in structurally weak areas and segment the image in the region of high strain. In previous work, we used commercial software VOXELCON, which is an image-based structural analysis system. In the approach examined, we set physical properties for every pixel and create a stiffness matrix. Then, we calculated the von Mises strain of every pixel and removed the one with the highest strain value, assuming it will be broken. We iterated strain calculation and removal until the input image is decomposed into multiple fragments. The method could be used to segment low-contrast CT images - a task that was difficult with conventional methods. This technique was based on the use of structural analysis for CT image segmentation. However, it was necessary with this approach to set boundary conditions manually in structural analysis. Thus trial and error is required to apply the method.

In this paper, we expand our previous work to set parameters and loading conditions in a semiautomatic way. We set regions of interest (ROIs) as candidates for weak areas, which include correct and erroneous segmentation targets. Assuming strain as an objective function, we calculate boundary conditions for each ROI using a gradient ascent method. In other words, we calculate strain for all ROIs. Then, we choose the ROI with the highest strain as the correct candidate for a weak area, and these conditions are then used to segment the image.

The main advantage of the proposed approach is its reliability, as the structural analysis it involves means that appropriate object segmentation in structurally weak areas is guaranteed. As this method is designed to segment joints of a skeleton and thus prefers such objects with shapes of relatively high aspect ratio around the segmentation boundaries. The originality of this research lies in its introduction of the analogy of mechanical destruction to image processing and its optimization of boundary conditions in the finite element method (FEM).

Green area in the top and left middle are ROI and the red arrows show some representatives of loading forces. Images in the right and middle

show distribution of von Mises strain and red pixels indicate high value. Using analogy of destruction we repeat removing these red pixels until the object gets separated along the interference region. In the bottom, the result of segmentation is shown where the removed pixels are salvaged to be included in the segments.
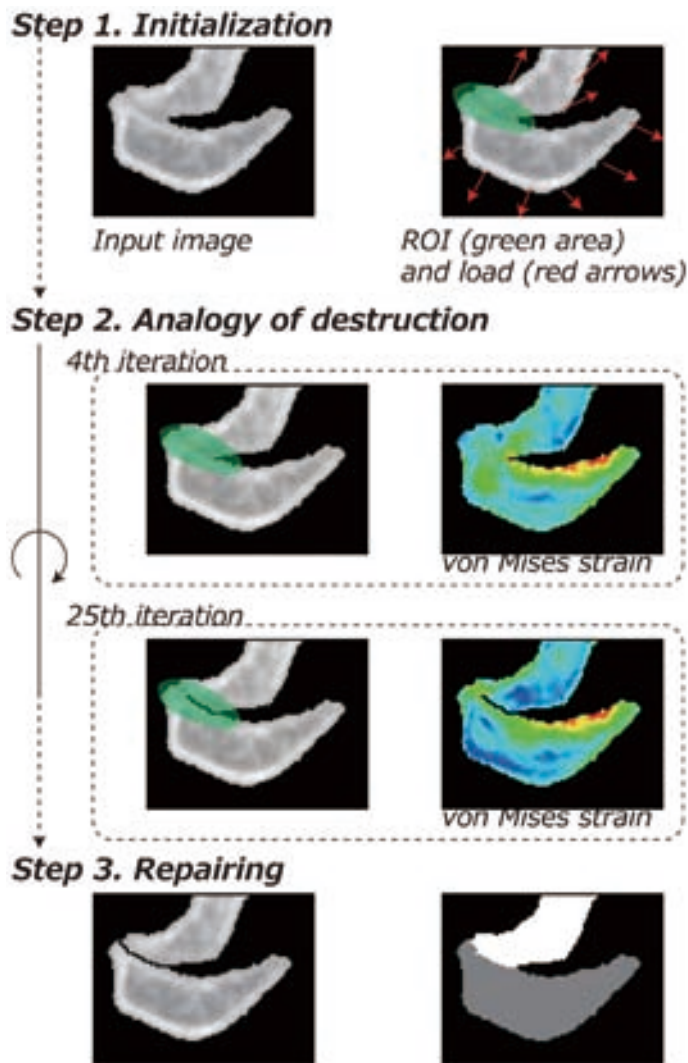

Step 1. Initialization

Input image

ROI (green area) and load (red arrows)

Step 2. Analogy of destruction

4th iteration

von Mises strain

25th iteration

von Mises strain

Step 3. Repairing

Figure 1. Flow chart of the proposed segmentation algorithm.

Cerebellar Size Estimation from Endocranial Measurements

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There is a broad consensus that higher cognitive functions in modern humans, including language, are supported by the well-developed neural bases, especially those of the cerebral region (e.g. Beaumont, 2008). On the other hand, an increasing number of neuroanatomical, clinical, and functional neuroimaging studies suggest that the cerebellum also contributes to cognitive functions (Murdoch, 2010; Stoodley and Schmahmann, 2010). Therefore, reliable data of cerebellar volume estimates of extinct hominins can be an important source in understanding when and how the neural bases related to higher cognitive functions evolved. Especially, whether Neanderthals were significantly different or not from modern humans in the cerebellar volume is an intriguing question because these two species differed in behavioral and cultural aspects (e.g. Klein, 2009) although they were largely comparable in the whole brain size (estimated from the endocranial volume) (Schoenemann, 2006).

The cerebellar volume of fossil hominins might be estimated from the posterior cranial fossa (PCF) (Figure 1). The PCF is a posteroinferior region of the endocranial cavity and a bowl-shaped depression that houses a substantial volume of the cerebellum. However, the relationship between the PCF and the cerebellum is not so simple; an anterior space of the PCF are occupied by the brain stem, while an upper portion of the cerebellum protrudes from the upper border of the PCF.

Cerebellar volume estimates of some fossil hominin specimens have been reported by the pioneering work of Weaver (2001, 2005). She estimated these by using the regression equation based on PCF volume of a mixed hominoid species sample (MRI data of 4 hylobatids, 13 great apes, and 17 modern humans) (Weaver, 2001), and she found that the Neanderthal specimens had smaller cerebellar volumes, relative to their whole brain size, than those of the living human sample (Weaver, 2001, 2005). She justified her estimation by the high correlation between the PCF and cerebellar volumes from MRI data ($r2 = 0.89$) (Weaver, 2001, 2005). However, the high correlation was probably due to a large range of variation in size from gibbons to humans, and it does not mean that the cerebellar volume estimates of the fossil specimens are accurate. The first author and co-workers re-examined the Weaver's dataset and found that correlation within the human sample (n=17) is actually weak ($r2 = 0.16$) and not significant (Kubo et al., 2011). Thus the suggested difference of the cerebellar volume between the Neanderthals and modern humans remains to be tested.
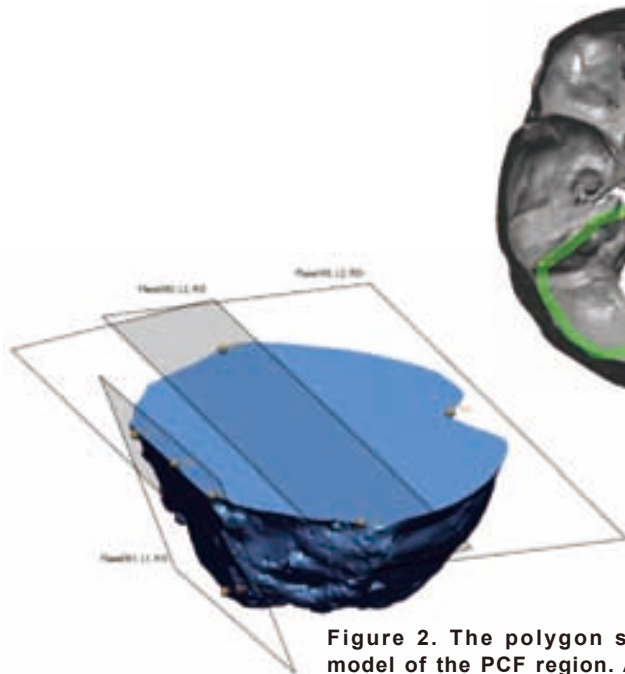
In order to develop estimation methods of the cerebellar volume and also clarify the limitation, we examine the correlation between the PCF and cerebellar volumes using MRI data of Japanese subjects (Figures 2 and 3). We found that the two volumes are more highly correlated in our dataset (Figure 4) than expected from Weaver's MRI data of the human sample. The PCF volume in our definition do not include the volume of the anterior part of the PCF region where the brain stem is located (Figures 2 and 3), and this could partly contribute to the high correlation with the cerebellar

volume. At any rate, the fact that a high correlation was confirmed in a modern human population could offer promising prospects for its application towards the other modern human and possibly Neanderthal examples.
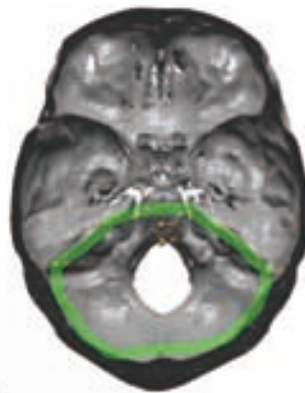
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Figure 1. Superior view of the lower half of an endocranial cavity, rendered from CT data. The PCF is the depression area surrounded by a green line.

Figure 2. The polygon surface model of the PCF region. An PCF region is first segmented from MR volume data, and then converted into a polygon surface model. The volume was measured after trimming by the anterior and superior planes defined by anatomical landmarks.
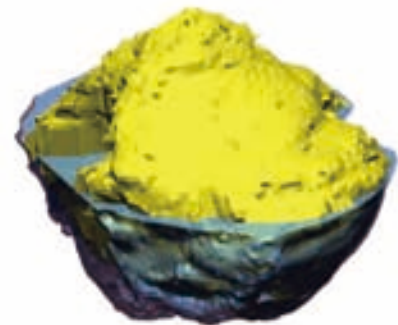
Figure 3. Superimposed image of the PCF region and cerebellum.
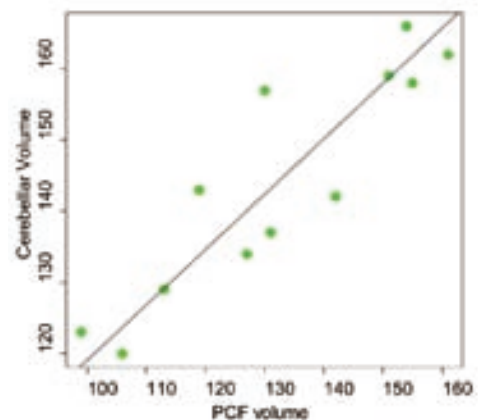
Figure 4. Bivariate plot of the PCF and cerebellar volumes with reduced major axis (a preliminary result based on a small number of sample).

Transferring Semi-Landmarks on Surfaces

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Introduction

Estimating the positions of semi-landmarks is important in analyzing the fossil crania [4]. While we can locate anatomical landmarks reliably, locating semi-landmarks consistently is a difficult task. This is because semi-landmarks are generally distributed around featureless regions and we cannot locate them using local shape descriptors.

To estimate the positions of semi-landmarks, we consider the problem of semi-landmark transfer in this research: given a surface mesh A (with landmarks P_A and semi-landmarks Q_A) and a surface mesh B (with landmarks P_B), transfer the semi-landmarks of A onto B. In other words, compute the positions of semi-landmarks Q_B of B using P_A, Q_A and P_B. We assume that $P_A = \{p^i_A\}_i =^k_1$ and $P_B = \{p^i_B\}_i =^k_1$ have the same size, and that each landmark p^i_A on A has a corresponding landmark p^i_B on B ($i = 1\ldots k$).

Sliding semi-landmarks [3] is the standard method in semi-landmark transfer. In this method, semi-landmarks are transferred so as to minimize the bending energy of the thin-plate spline warp [2] between $P_A \cup Q_A$ and $P_{BA} \cup Q_B$. We also use an energy minimization approach, but we minimize the bending energy over the surface instead of over the whole 3D space (which is the case of sliding semi-landmarks).

Method

We assign an Affine transformation to each vertex of the mesh as in [1] and compute it by minimizing the bending energy. Since the landmarks P_A on A corresponds to the landmarks P_B on B, we set hard constraints: P_A is transformed to P_B. This constrained optimization can be solved by the Lagrange multiplier method and it reduces to the linear system as shown in [5].

Let

$$\begin{pmatrix} a^i_{1,x} & a^i_{2,x} & a^i_{3,x} & a^i_{4,x} \\ a^i_{1,y} & a^i_{2,y} & a^i_{3,y} & a^i_{4,y} \\ a^i_{1,z} & a^i_{2,z} & a^i_{3,z} & a^i_{4,z} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

be the Affine transformation assigned to the i-th vertex of the surface mesh A. Then, for x-coordinates, we solve the following linear system:

$$\begin{pmatrix} (L^{T^2}L^2) \otimes I_4 & C^T \\ C & O \end{pmatrix} \begin{pmatrix} a_x \\ \lambda_x \end{pmatrix} = \begin{pmatrix} 0 \\ b_x \end{pmatrix},$$

where L is a Laplacian matrix, $\cdot$ denotes the Kronecker product, I_4 is the identity matrix of size 4, a_x is a variable that corresponds to the Affine transformations, C $a_x = b_x$ is the set of the hard constraints, and λ_x is the Lagrange multipliers. Specifically,
$a_x = (a^1_{1,x}, a^0_{2,x}, a^0_{3,x}, a^0_{4,x}, a^2_{1,x}, a^2_{2,x}, a^2_{3,x}, a^2_{4,x}, \ldots)^T$. $L^{T^2}L^2$ corresponds to the bi-Laplacian system, and the i-th row of C $a_x = b_x$ corresponds to the constraint that p^i_A is transformed into p^i_b ($i = 1\ldots k$). The linear system is large and sparse, and its size is $(4n + k)\times(4n + k)$, where n is the number of the vertices of the surface mesh A and k is the number of the landmarks. We have similar linear systems for y- and z-coordinates. By solving these three linear systems, the Affine transformations of the vertices are obtained.

Note that, since the coefficient matrices of the

linear system for y- and z-coordinates are the same as that of the linear system for x-coordinates, we can reuse the decomposition results to save the computational time of the linear solves.

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A Geometric Morphometric Study of Neurocranial Shape Variations in the Crania of Modern Japanese

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Geometric morphometrics have been widely used for the analyses of morphological variabilities in human crania. However, morphological variability in the neurocranial shape has not been well documented because only a few definable landmarks exist on the human cranial vault. In the present study, we analyzed the morphological variability of the neurocranial shape in the modern Japanese population using the sliding semi-landmark method.

We used a total of 60 crania (27 female and 33 male crania) from the modern Japanese population housed at Kyoto University. Each cranium was scanned using a CT scanner and the 3D surface model of the cranium was generated. Template landmark configuration that will be projected onto and slid along each of the samples was prepared based on the shortest paths connecting pairs of anatomical landmarks. Specifically, conventional anatomical landmarks and equally spaced points along the superior nuchal curve and temporal curve are defined as non-sliding landmarks. These non-sliding landmarks as well as equally spaced points along the midsagittal curve and the frontal torus were used to calculate the shortest paths as shown in Figure 1A and the equally spaced points along them were designated as sliding semi-landmarks. Therefore, the template landmark configuration consisted of a total of 121 sliding and non-sliding landmarks. In the present study, Templand in the EVAN Toolkit (http://www.evan-society.org) is used to calculate the

positions of the sliding landmarks on each of the specimen. The coordinates of the landmarks were then analyzed using Morphologika (http://hyms.fme.googlepages.com/resources). The landmark coordinates were normalized by centroid size and registered using the Generalized Procrustes Analysis. Principal components (PCs) of shape variations among the specimens were then calculated using the variance-covariance matrix of the Procrustes residuals of all crania.

Figure 1B shows the variations in the 3D shape along PC1 by warping the neurocranial shape represented by the wireframe connecting the landmarks. The PC1 accounted for 24.1% of the total variance. We observed that with increasing PC1, a relative contraction of the cranial length and relative elongation of the cranial breadth were observed. Particulary, the forehead and occipital region had receded and the nuchal lines were located relatively located more inferiorly with an increase in PC1. We demonstrated that the most predominant shape variability in the cranial vault in the modern Japanese population is the brachycephalic/dolichocephalic tendency. We will use this detailed quantification method of the human neurocranial shape to construct a morphological database of human cranial shape, which is indispensable for mathematical reconstruction of fossil crania.
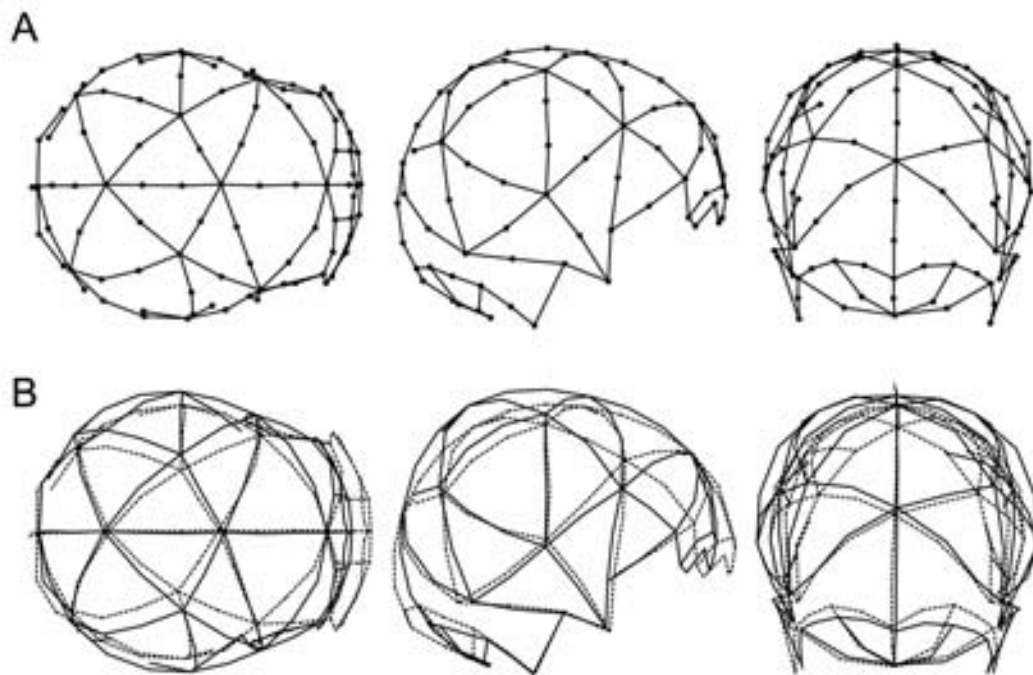
Figure 1. (A) Template landmark configuration. (B) The variation in neurocranial shape represented by PC1.

Motion Analysis for Stone-Knapping of the Skilled Levallois Technique

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Introduction

An investigation of skilled behavior is important to clarify a cognitive mechanism of learning process. In this research, we measured 3D motions of stone-tool production based on the recurrent Levallois technique by a highly skilled subject. And, a motion analysis of measured kinematic information was performed. To combine the analysis based on the experimental archaeology, it will be available to extract body motions which is represented the skilled behavior and to estimate a force necessary for processing of Levallois points (LP) and Levallois flakes (LF). We would like to report the analysis results about expert technology of Levallois. In January 2011, we acquired the motion of the chipped stone tool using the motion capture system. In this experiment, the subject is expert master of Levallois technique. The subject formed code's edges at one end. After that the subject pick up a target flake by flaking off pieces around the outline of the intended flake. The subject creates those flakes by strike hammer-stone repeatedly. On using the motion capture system, three tracers are put around the target subject. The tracers took 3D motion data subject and hummer stone. Those data has included the acquisition peeling operation. On the research project of "Replacement of Neanderthals by Modern Humans: Testing Evolutionary Models of Learning", our research reported analysis result of video images and analysis of illocutionary acts by interview of the subject. In the past on this project, we have reported analysis results using interview the subject about operation process and thinking points with the detail motion data and the fabrication characteristics of the

action getting Levallois flakes. In this project, learning process is main topic. Learning (education) is for the survival of mankind. Archaeological material is the only evidence that indicates the learning behavior of prehistoric times. We collect and analyze the archaeological materials and want to find out what's the difference between human beings and the New Learning of archaic humans. Levallois technique and skill is one kind of the archaeological materials. Modern humans begins with a cognitive behavior in specific, they obtained this skill during short time at 250,000 years to 6 million years. We are considering that those are from the evolution and a group production by mixing the group learning and the individual learning.

Two process of Levallois technique for the motion analysis

It is important to analyze how skill is acquired, in order to understand human's learning ability. In this study, we analyzed a difference of kinematic information of hand motion between each procedure to construct a stone-tool by the Levallois technique from a 3D motion data measured from a skilled subject. For those analyses, we consider 2 level processes about Levallois technique, See Figure 1. We catalogs two process data classes. The first process is a beat knapping to make a form called a stone testudinal style. Second process is a strong knaps to flake off a piece. So, ① is in the process of forming the testudinal style by finely knap. The core stone is deformed visually by a beat knapping, so the former is possible to check visually and acquired by social imitation. The knapper

should proceed with consideration of the flakes in the process of acquisition of ② it is predicted to advance (prediction) the transition state to the process of ②. Our discussions would not touch here in this paper. This is consideration point using experiential knowledge. We should the future work for analysis and research. The rehearsal experiment is 1time. Then, we conducted a full-scale experiment. After lunch, I conducted a final experiment. LP motion is trying behavior to get the object have a projectile point. This object are such as a spear, dart, or arrow, or perhaps used as a knife. If the knapper has an image that behavior, the knapper makes an announcement "LP" in the experiment. LF motion is trying behavior to get the flakes objects. If the knapper has an image that behavior, the knapper makes an announcement "LF" in the experiment. In the rehearsal, the knapper tried 5 times knap for LP / LF. This case, total knap is 28 times during 11 minutes. In the first experiment, the knapper tried 14 times knap for LP / LF. This case, total knap is 52 times during 27 minutes. In the final experiment, the knapper tried 16 times knap for LP / LF. This case, total knap is 66 times during 55 minutes. The knapper was carefully shaping the stone. After that, the knapper hit strongly. Is this same process of Neanderthal? or Modern humans?

Analysis about getting to LF motion

In this paper, we have processed a detailed analysis of behavior. Our focusing is the operation at the time of getting flakes. Figure 2 is the marker position and hummer stone in this experiment. When knapper gives us declaration for getting flakes, he always selected most lightweight stone, 115[g]. This is likely to be a result of determining the controllable easy than the power impact. Additionally, No.3 marker is representing the movement of the stone. Figure 3 is an example of a photo. Before the motion, knapper declared the process of getting LF. We would be able to see the behavior twisting the wrist, and then see the behavior the pull behind the elbow. Figure 4 is a graph of impulse on the hammer stone at getting FL. This impulse curve explains the big impact and hitting stone. After this impact, stone speed has changed slowly. Therefore for getting LF, the knapper takes a

decision this impulse value necessary. See Figure 4 and 5, the direction of the impulse is changing rapidly between about 0.35-0.55 [sec]. This area is a curve after the stone hammer collides with the stone. The impulse reaches to target stone by the momentum conservation law. It shows that the knapper is accelerating at the same time pulling the elbow and twist of the wrist. Figure 6 shows the torque applied to the hammer stone vector. Near the impact point, the torque vector is a direction different from the direction of travel of the hammer stone. We let discuss this area. We can consider the vector direction of this graph is due to a twist of the wrist. In order to obtain a constant speed of this very short time, twisting of the knapper operation is to take full advantage of the human skeleton. This twist makes a small shift of hit points. A greater speed is controllable easy for the small skeleton. If the skeleton is strong, the twist operation increases a shift of hit points. In order to suppress the deviation that knapper must slow down. If the hammer stone heavier then, knapper can make the impulse of the same degree. Skeletal differences make a difference hummer selection and hitting speed to target stone. In other words, 3D graph and light weight hummer-stone explain that modern small person represents the clever control arm than the strong skeleton people like Neanderthal.

Discussion

We are considering that Homo sapiens have survived by twisting motion and the clever control arm. This is a necessary element of both individual learning and social learning. To determine the LP and LF motion is particularly important individual learning. The individual learning is the most important and necessary long time learning. This learning method is highly suitable for modern people life. We assumed to assist the operation of swinging the arm acceleration to pull the elbow. Neanderthals were 80-90 kg body weight, height 160 cm. Their muscles were well developed. They also had strong bones. We speculate that they are inferior the ability of learning and did not control the twist of the arm. Therefore, we believe that they were making crushed stone instinctively as the recurrent Levallois technique. In addition, the

life expectancy of the Neanderthals is about 20 years old, they were short-lived. The Knowledge accession to the next generation has been hard. In the future, we will proceed with the investigation and analysis of the literature. We will be looking for a material that represents the difference between the learning ability between Neanderthal and modern human.
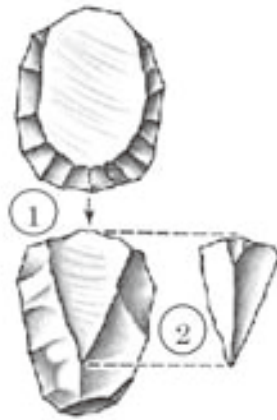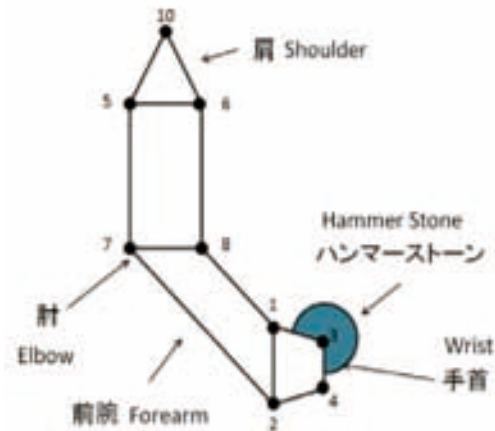

Figure 1. Two processes of Levallois technique.
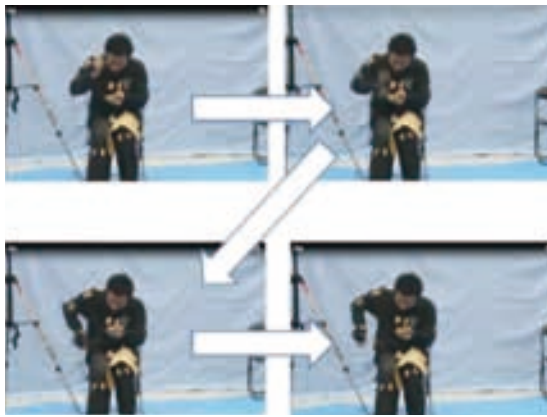

Figure 2. Motion marker position and stone.

Figure 3. Motion pictures of hitting strongly.
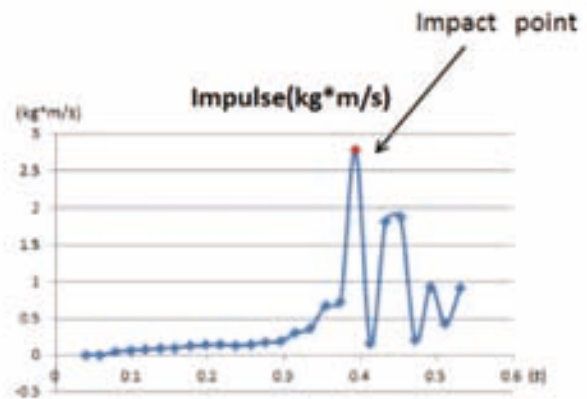
Figure 4. Impulse curve getting LF.
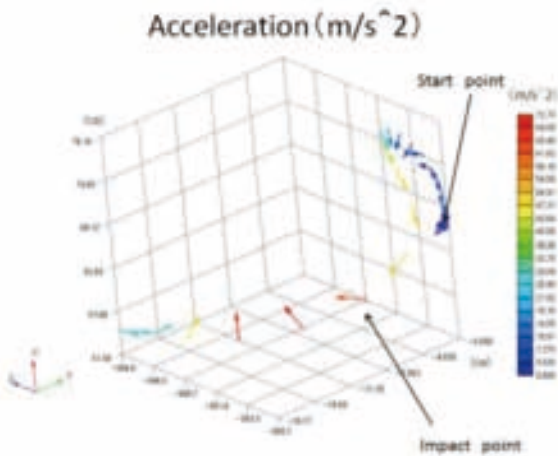
Figure 5. 3D acceleration curve No.3 marker.
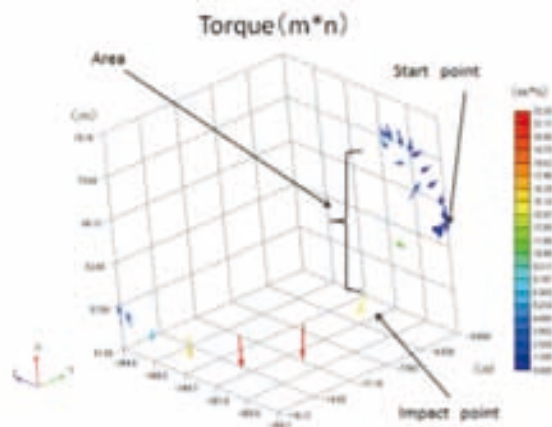
Figure 6. Direction vector of the rotational torque around hammer-stone.

Brain Activation Related to the Imitative Learning of Bodily Actions Observed during the Construction of a Mousterian Stone Tool: A Functional Magnetic Resonance Imaging Study

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Introduction

An elucidation of cognitive abilities underpinning social learning behavior are important to comprehend the human evolutionary history, especially for inheritance of technology, because inheritance of technology is realized by learning the information about the behavior of other individuals and its products through several kinds of social interactions among individuals such as imitation of the others' behavior. Previous studies suggested that the mirror neuron system including Broca's area commonly participates in neural basis of tool-use and language, accordingly it is considered that the neural basis of those cognitive function have common developmental process. However, there is no direct evidence about which component of neural basis of tool-use played a key role in the process of social learning to acquire novel technology from others. Especially, it is unknown in whether an acquisition of cognitive ability for tool-use via the social interaction on prehistorian age was intervened in the learning ability for linguistic information. In this study, we focused a neural mechanism to learn a novel technology such as stone tool-making through an observation of others' behavior, and existence of shared neural mechanism with learning of linguistic information.

We hypothesize that the stone tool-making can be learned by observation of the others behavior, and that neural mechanism contains different neural components compared with the imitative learning of spoken language. To verify the hypothesis, we used functional magnetic resonance imaging. The experimental task was consisted a repetitive observation of the stone tool-making, and that of unknown word-pronunciation.

Materials and Methods

Twenty-four healthy Japanese volunteers participated in this study (12 males and 12 females, mean age: 25 ± 5, range: 20–36 years). The experimental data from six subjects were excluded because of excessive head movement or an insufficient number of responses. Thus, we analyzed data from 18 participants (nine males and nine females). All participants provided written informed consent to an experimental protocol approved by the Ethical Committee of the National Institute for Physiological Sciences. The authors also declare that all experiments on human subjects were conducted in accordance with the Declaration of Helsinki.

The fMRI experiment consisted of four runs of actual measurement and one practical run. A rapid event-related design was used for the fMRI experiment. During fMRI session, all participants observed 15 moving pictures and one still picture of stone tool-making and 15 moving pictures and one still picture of the pronunciation of an Uzbek word. Each picture showed a kind of bodily action used to make a Mousterian stone tool or to

pronounce one Uzbek word. Each moving picture was presented twice in each run. The practical run presented moving pictures that differed from those used in the actual run. The pictures were separated by resting intervals of approximately 4 sec, during which time a white fixation cross was presented.

Participants were instructed to observe the pictures and to memorize the content of the bodily action or word pronunciation. To ensure that the participants were conscious of the task, an actual imitation task was conducted immediately after the fMRI measurement. To confirm the arousal state of the participants, the color of the fixation cross occasionally changed to yellow, and the participants were instructed to press a button when they noticed the change. Figure 1 illustrates a timeline of an fMRI run.

Data preprocessing and statistical analyses of fMRI data were performed using statistical parametric mapping (SPM8, Wellcome Trust Center for Neuroimaging, London, UK). The fMRI data were analyzed using a two-stage approach. During the first stage, the hemodynamic responses produced under the different experimental conditions were assessed at each voxel on an intra-subject basis using a general linear model. The second stage of analysis was performed on an inter-subject basis using a two-way repeated-measures factorial design. One factor was the type of picture observed, and the other factor was the number of times the same moving picture was presented repeatedly. To identify the regions showing learning effect for each task, contrast images representing a repetition suppression effect of task-related activation were created and estimated. The statistical threshold was set at $p < 0.05$ (corrected for family-wise error (FWE) by voxel level).

Results and Discussion

We found task-specific cortical activation of the parietofrontal network during the observation of stone tool-making. A recent meta-analysis of action-observation and imitation tasks also reported similar patterns in cortical networks (Caspers *et al.*, 2010). The results suggest that the cognitive mechanism to manipulate the self-motor representations contributes in the action observation during the imitative learning. By contrast, the bilateral premotor area and superior temporal gyrus were activated during the observation of word-pronunciation. Previous neuroimaging studies of phonological processing reported that the inferior part of the dorsal premotor area plays an important role in the articulatory process (Brown *et al.*, 2009), and the posterior part of the superior temporal gyrus is important for audiovisual speech perception (Murase *et al.*, 2008), thus supporting our conclusion that the activation we observed in the bilateral superior temporal gyrus was induced by perceptions of the pronunciation of the Uzbek word.

The learning-related activation change during observing the stone tool-making was shown in the right cerebellum (Figure 1(a)) and that of word-pronunciation was shown in the left superior temporal gyrus (Figure 1(b)). The result suggested that the progress of imitation learning was represented on the specific cortical region, and the represented region was dependent on the information which the subject focused to learn. A previous study reported that the changes of activity in cerebellum reflects a progress of internal model formulation to learn a motor control to manipulate a novel tool (Imamizu *et al.*, 2000), whereas the repetition-related decreases in the left superior temporal gyrus reflected the effect of learning on the neural processing of the perception of auditory stimuli (Rauchecker *et al.*, 2008). By contrast, the common activated regions of both observation tasks are not influenced by progress of imitative learning.

In conclusion, the progress of imitative learning on stone tool-making and word–pronunciation were represented activity of different neural mechanism instead of common neural mechanism between them. Therefore, the result indicate that the progress of imitation learning for the stone tool-making and word-pronunciation

were represented on the specific cortical region respectively, and the represented region was dependent on the information which the subject focused to learn.

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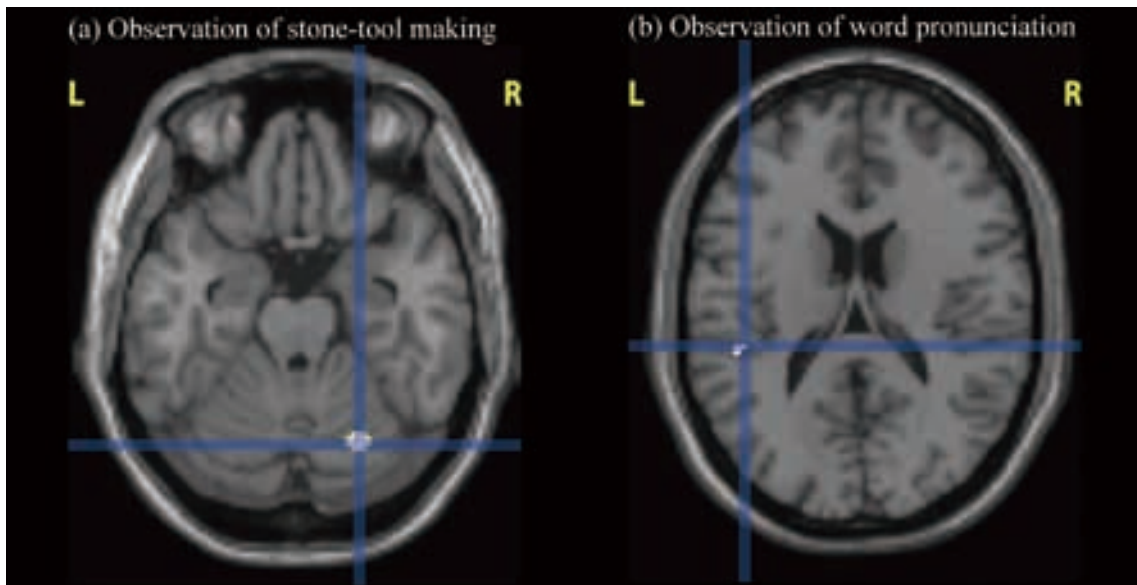
Figure 1. Cortical region showing repetition-suppression effect in the (a) right cerebellar posterior lobule with task-related activation during observation of stone-tool making, and (b) in the left superior temporal gyrus with task-related activation during observation of word pronunciation.

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