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The Role of Analogical Abduction in Skill Acquisition

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Abstract. We discuss the effectiveness of analogical abduction in skill acquisition. Abductive inference makes it possible to find missing links that explain a given knack in achieving a skillful task. We introduced meta level abduction to realize rule abduction which is mandatory in finding intermediate missing links to be added in knack explanation. Analogical abduction can be achieved by adding analogical inference rules to causality meta rules within meta level abduction. We have applied our analogical abduction method to the problem of explaining the difficult cello playing techniques of spiccato and rapid cross strings of the bow movement. Our method has constructed persuasive analogical explanations about how to play them. We have used a model of forced vibration mechanics as the analogy base world for spiccato, and the specification of the skeletal structure of the hand as the basis for the cross string bowing technique. We also have applied analogical abduction to show the effectiveness of a metaphorical expression of "eating pancake on the sly" to achieve forte-piano dynamics, and successfully identified an analogical explanation of how it works. Through these examples, we show the effectiveness of analogical abduction in skill acquisition. Furthermore we discuss the importance of meta level representation as a basis for providing rich human cognitive paradigm such as causality, analogy and metaphor.

Keywords: rule abduction, analogical abduction, predicate invention, predicate identification, cello playing

1. Introduction

In acquiring skills in such activities as sports, playing instruments, drawing picture and so on, it is essential to get some sort of "knack" to perform those activities. The notion of achieving a knack refers to some kind of unexplained but necessary skill component, without which performance is lacking. In acquiring

professional skill, it is said that we need continuous daily training or practice something like 10,000 hours. However it is very hard to spend such long period of time for ordinary people, like amateur athletes or musicians. For those people, the key strategy is to acquire some critical knack for achieving those skills. There are many possibilities in acquiring a knack, e.g., observing professionals' performance, being taught by trainers, conducting trial and error by themselves and so on. Such training methods have two important features in their processes; encountering a knack and assimilating and/or accommodating the knack. Trainers' suggestions are quite useful to encounter key points which play essential roles in understanding the knack. Observation of professionals' performance sometimes makes it possible to acquire an ideal form of performance which may give a solution for achieving the given task. Trial and error is useful to finding key points to realize the task and to get the knack by themselves. It is always important for the players to consider how the performance task is related to possible activities that can achieve the goal. For such mental activities, abduction and analogy play central roles in deepening the thinking that relates the problem with various activities which may not always be directly related to the problem domain. In Particular, analogical reasoning is quite useful to expose relationships which may not be directly related in the performance domain in question.

Knacks play crucial roles in acquiring artistic or sports skills. Generally knacks themselves are hard to understand. This is the reason why we call the secret as knack to perform difficult tasks. Abduction is a kind of synthetic reasoning used to construct explanatory hypotheses about knacks i.e. surprising observations. In this paper, we show how we have succeeded in applying abductive inference to provide explanation structure about how to perform difficult cello playing techniques, by exposing "hidden secrets" behind a given "knack" for achieving a difficult task.

Furthermore, we try to give proper explanation of a knack by employing analogical abduction. The role of abduction is to find explanation structure i.e. missing links in the explanation, whereas that of analogy gives understandable explanation to either the knack itself or the introduced links.

In realizing the analogical abduction engine, we integrate abduction and analogy on the basis of meta level expression of causality and analogy.

In Chapter 2, we discuss aspects of skill discovery in skill acquisition, focusing on two approaches; "meta cognitive verbalization" and "analogical abductive reasoning". In Chapter 3, we give formulation of skill acquisition by abduction. In Chapter 4, we augment abduction by analogy. In Chapter 5, we discuss other possibilities for explaining knacks. Lastly, in Chapter 6, we conclude our paper.

2. Aspects of Skill Discovery in Skill Acquisition

In acquiring any kinds of skill, an essential point is the mental activity of trying to discover a knack to perform a given difficult task. Knack discovery is essential

in skill acquisition. Previously, we found the importance of closing one's right arm to increase sound volume in playing the cello as a case study [1, 2]. This is an example of a knack. Later, we discovered another knack to increase the sound by tilting the bow to touch to the string by the edge of the bow hair, which we call the "edge bowing method". These knacks provided significant improvement in achieving the given task.

The verbalization of a knack helps one to be more confident about acquired skills, both to deliver them to other people and to make them more objective. Among several approaches of skill verbalization, we especially notice two methods; "meta cognitive verbalization" [3, 4] and "analogical abductive reasoning" [5]. Meta cognitive verbalization tries to memorize one's physical status during performance in terms of notions which appeared in one's mind by self-reflection. By accumulating those memos for a long period of time, one can discover important facts within the change of vocabulary usage patterns, which reflects skill development.

On the other hand, analogical abductive reasoning tries to extract possible explanations how to perform given hard tasks by selecting adequate combinations of candidate hypotheses in a repertoire of body movement actions. For example, in our experimental study, we tried to find methods to perform "traverse between two strings repeatedly with bow direction change" and discovered a hypothesis "activate right forearm muscles strongly".

Skill acquisition has many issues to be addressed. Some are listed as follows;

i. finding a knack for skillful performance,
ii. finding missing links (secrets behind a knack) in skill explanation,
iii. identifying the role of a surprising fact (a knack) in skill discovery, and
iv. accommodating the new skill.

Interestingly, most of the issues listed above can be properly treated in the analogical abductive reasoning framework. In this paper, we focus on the skill of playing the cello. A player often exercises some basic methods at the first step of training. In some later steps, however, the player may face a passage which s/he cannot play by using only acquired methods. In such case, none of the acquired methods can be applied to the passage, so new methods are required. Typically, the passage in question contains compound tasks to be achieved simultaneously. In that case, simple adoption of component basic skills do not work properly; we need to invent a new skill to avoid potential inconsistency amongst the compound tasks: we call this process *skill abduction*. The new skill is called an abduced skill. The solution may be unexpected and hard to achieve. Our goal is to aid the player and/or the trainer to find a solution by analyzing the goal task, basic skills and relevant physical constraints.

3. Formulating Skill Acquisition by Abduction

3.1 Generating hypotheses by abductive reasoning

Although abductive reasoning does not necessarily derive the right answer, it produces plausible hypotheses to explain observation and therefore useful in hypotheses generation. The philosopher Pierce first introduced the notion of abduction. In Pierce [6] he identified three forms of reasoning.

Deduction, an analytic process based on the application of general rules to particular cases, with the inference of a result.

Induction, synthetic reasoning which infers the rule from the case and the result.

Abduction, another form of synthetic inference, but of the case from a rule and a result.

Peirce further characterized abduction as the "probational adoption of a hypothesis" as explanation for obsevations (results), according to known laws. "It is however a weak kind of inference, because we cannot say that we believe in the truth of the explanation, but only that it may be true" [6]. We omit formal definition of abductive inference to avoid complexity [7]. The essence of abductive inference is to augment missing facts or rules to derive the given surprising observation (the knack). Therefore an abductive inference engine is synonymous with a theorem prover augmented by a mechanism of finding missing links in deriving the given problem (a knack).

3.2 Logical explanation of a knack by abduction

Knacks are target-dependent and are expressed by such phrases as "if you want to achieve a target exercise *A*, you should do an action *B*." But it is typically difficult to explain why the action *B* works for achieving the exercise *A* because of either the existence of "hidden secrets" behind the knack or the lack of proper knowledge to understand the given knack. In this section we solve the former problem by applying abduction. The latter problem is solved in Chapter 4.

A knack is usually a surprising observation and therefore hypotheses generation by abduction can help in finding candidates for the "secret" prerequisite for achieving the given exercise. To elaborate, we try to abduce missing hypotheses to achieve (explain) the goal (exercise) *A* under the assertion of the fact (action) *B*. Since *B* appears at the leaf of the proof tree, the abduction procedure has to find hypotheses in between the goal *A* and the leaf *B*, identified as a (set of) rule(s). We refer to this abductive procedure as rule abduction. Note that rule abduction itself is realized in the framework of ATMS (Assumption based Truth Maintenance System) [8]. In this paper, we select logic programming approach because it is simpler and more expressive than ATMS. However, rule abduction cannot be achieved by standard Abductive Logic Programming (ALP) [7], because "abduci-

bles" (predicates which are allowed to appear in the hypotheses to be generated) are limited only to "facts" in ALP. It means that generated hypotheses are simple (unknown) facts. A simple example of fact abduction is to explain the lack of a person's alibi by hypothesizing that he is a criminal. This limitation is due to the difficulty of handling rule abduction. To resolve this difficulty, we developed a rule abduction method using meta level abduction [2] where causality relations between predicates are expressed by a meta predicate "caused(*X,Y*)" which represents that the goal *X* is caused by an action *Y*. Note that we restrict the logical implication to causality. The detail of the meta level representation is described in the next section.

There may be a situation where a (set of) intermediate proposition(s) is necessary to fill a gap between the premise B of the knack and its goal A, in which case we need to invent a new node (predicate) between them. This ability is called as "predicate invention" in Inductive Logic Programming (ILP) community, which has been claimed to be very hard to realize. We found that SOLAR was equipped with this function naturally by virtue of the ability to produce hypotheses having variables with existing quantifier [2]. An example having his feature is shown later in subsection 4.3.2.

3.3 Meta level representation for rule abduction

A weakness of available abductive inference engines such as PrologICA [9] is that we can only abduce facts but not rules. As explained in the last section, we need rule abduction to explain why knacks work. Our approach to overcome this problem is to introduce meta level representation to express rules as atoms by introducing causality relations between predicates such as *caused*(*spiccato*, *bow_support_with_ringfinger*), which states that spiccato is caused by supporting the bow with the ring finger. This representation allows us to state a rule "spiccato is caused by supporting the bow with the ring finger" in terms of a meta level atom *caused*(*spiccato*, *bow_support_with_ringfinger*). Since we can abduce meta level atoms with a predicate *connected* (which represents a direct causality relation) by applying conventional abductive engines, we succeed in obtaining a rule "$spiccato \leftarrow bow\_support\_with\_ringfinger$." Formally, the predicate *caused* is defined recursively as follows:

$$caused(X,Y) \leftarrow connected(X,Y) \quad (1)$$
$$caused(X,Y) \leftarrow connected(X,Z), caused(Z,Y) \quad (2)$$

Here, the predicates *connected* and *caused* are both meta-predicates for object-level propositions *X*, *Y* and *Z*. From now on, we refer to this representation of causality relations as Meta Level (ML) representation of causality.

4. Augmenting Abduction by Analogy

4.1 Why analogical abduction?

Our rule abduction alone is insufficient to obtain meaningful missing prerequisites in the real application domain of skill acquisition. For example, consider this example of a knack: "you should bend the thumb joint to realize crossing strings quickly." In this example, a possible missing rule is the knack itself; that is, "to achieve crossing strings quickly, bend the thumb joint" is a rule to be hypothesized by rule abduction. But it is easy to see that this rule is essentially useless because it does not explain why it works effectively. Here we introduce an analogical abduction system which makes it possible to give a suitable explanation to the proposed knack. To show the effectiveness of the knack, we need to identify a hidden reason. The hidden reason is typically provided by analogical reasoning which gives a possible explanation of the knack by means of an argument in an underlying analogical domain associated with the original vocabulary of the abducible rules.

Abductive reasoning generates possible hypotheses to prove a given knack to achieve a given difficult task. However it proposes only a possible proof (explanation) structure, i.e., the identification of missing links in the proof tree. It remains the user's task to give an appropriate meaning to generated hypotheses. Analogical reasoning is a possible way to automatically identify potential meanings of generated hypotheses. For example, to give an explanation to the hypothesis "spiccato is directly caused by *bow_support_with_ringfinger*, we use an analogy to the dynamics of forced vibration which is known to be analogous to spiccato, that is, a fast jumping staccato. Furthermore we know that the forced vibration is directly caused by both supplying energy to the system with appropriate timing (just after the point of maximum amplitude) and absorbing shock at the point of energy supply. It is quite persuasive if we find a correspondence of *bow_support_with_ringfinger* to shock absorbing in forced vibration. We try to extract this correspondence automatically by incorporating analogical reasoning into an abduction engine SOLAR [10, 11].

4.2 Incorporating analogical reasoning to abduction

In this section, we incorporate analogical reasoning into our ML framework. We refer to the world under consideration as the target world and the corresponding analogical world as the base world. Analogical reasoning is achieved by introducing a base world similar to the target world, where we conduct inference [12]. Analogical reasoning can be formulated as logical inference with equality hypotheses [13]. We achieve analogical abduction by extending our ML based rule abduction framework.

We modify the causality relationship formula (1) and (2) to deal with causalities in the different worlds separately as follows:

$$
\begin{aligned}
&t\_caused(X,Y) \leftarrow t\_connected(X,Y)\\
&t\_caused(X,Y) \leftarrow t\_connected(X,Z),\ t\_caused(Z,Y)\\
&b\_caused(X,Y) \leftarrow b\_connected(X,Y)\\
&b\_caused(X,Y) \leftarrow b\_connected(X,Z), b\_caused(Z,Y)
\end{aligned}
\tag{3}
$$

where the prefix "*t"* represents a predicate in the target world and "*b"* in the base world. Although the predicate "*b_caused*" does not appear in following examples, we define it because of the symmetry with "*t_caused*" for possible future use. We also introduce a predicate "*similar*(*X, Y*)" to represent similarity relations between an atom *X* in the target world and a corresponding atom *Y* in the base world.

Now we have to define the predicate "*t_connected*," for which we have to consider three cases to show the connectedness in the target world as follows:

$$t\_connected(X,Y) \leftarrow connected\_originally(X,Y) \tag{4}$$

$$t\_connected(X,Y) \leftarrow connected\_by\_abduction(X,Y) \tag{5}$$

$$
\begin{aligned}
t\_connected(X,Y) \leftarrow\ & connected\_by\_analogy(X,Y) \wedge\\
& print\_connected\_by\_analogy(X,Y)
\end{aligned}
\tag{6}
$$

The first case is that the connectedness holds from the beginning, (4); the second case is that it holds by abduction as a solution of abductive inference, (5); and the third case is that it is derived by analogy, (6). Definition (6) contains an auxiliary predicate "*print connected by analogy*(*X, Y*)" which indicates that it is to be "*printed*" as a part of an abduced hypothesis to provide evidence that the analogical connection is actually used to show the "*t_connected*"ness. Since analogical reasoning can be achieved without any defects in the inference path, we need to prepare an artificial defect atom "*print_connected_by_analogy*(*X,Y*)" on the reasoning path. This printing in turn is defined by specifying the predicate "*print_connected_by_analogy*" as an abducible predicate.

We have to further define three predicates; "*connected_originally*", "*connected_by_abduction*" and "*connected_by_analogy*". The predicate "*connected_originally*" is used in the assertion of facts representing the original connection; "*connected_by_abduction*" is introduced as an abducible predicate. Finally, the definition of "*connected_by_analogy*" is given by the following analogy axiom which plays a central role in analogical abduction.

Analogy Axiom

$$
\begin{aligned}
connected\_by\_analogy(X,Y) \leftarrow\ & b\_connected(XX, YY),\\
& similar(X,XX), similar(Y, YY)
\end{aligned}
\tag{7}
$$

This axiom states that the nodes *X* and *Y* in the target world can be linked by the predicate "*connected_by_analogy*(*X, Y*)" because of the base relationship "*b_connected*(*XX, YY*)" between *XX* and *YY* which are similar to *X* and *Y*, respectively, as shown in Figure 1. Note that there may be more than one similarity can-

didates. In this paper, we assume that the user provides some of the initial similarities, and that the abductive inference engine will compute any remaining possible similarity hypotheses to explain an observation.

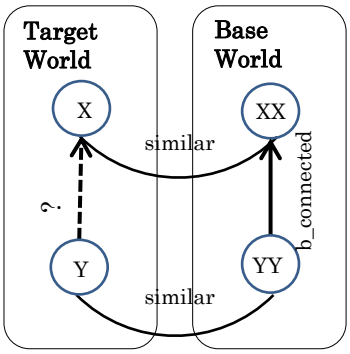

Figure 1 A schema representing the Analogy Axiom.

4.3 Giving analogical explanation to generated hypotheses

4.3.1 Interpreting a causal link by analogy

We first start with an example of a simple analogical abduction. The problem is ho to explain the effectiveness of holding the bow by the ring finger.

```
% Observation (G) :
t caused(spiccato, support_bow_with_ringfinger).                    (8)
% Abducible predicates( Γ ) :
abducibles([connected_by_abduction/2, similar/2,
print_connected_by_analogy/2]).
% Background Knowledge(B) :
%%% Base world:
b_connected(forced_vibration, shock_absorber).                      (9)
%%% Target world:
:-connected_by_abduction(spiccato, support_bow_with_ringfinger).    (10)
% Similarity:
similar(spiccato, forced_vibration).                                (11)
%Axioms:
b_caused(X; Y):-b_connected(X, Y).
b_caused(X, Y):-b_connected(X, Z), b_caused(Z, Y).
t_caused(X, Y):-t_connected(X, Y).
t_caused(X, Y):-t_connected(X, Z), t_caused(Z, Y).
t_connected(X, Y):-originally_connected(X, Y).
t_connected(X, Y):-connected_by_abduction(X, Y).
t_connected(X, Y):-connected_by_analogy(X, Y),
                    print_ connected_by_analogy(X, Y).
```

connected_by_analogy(X, Y):-b_ connected(XX, YY), similar(X, XX),
similar(Y, YY). (12)

In this program, the goal (observation) to be satisfied is "t_caused(spiccato, support_bow_with_ringfinger)" (Clause 8). We provide the following two facts: 1) "shock_absorber" is one of the possible causes to achieve the forced_vibration (Clause 9), and 2) spiccato is analogous to the forced_vibration (Clause 11). In addition, we provide a negative clause asserting that the direct connection from "support_bow_with ringfinger" to "spiccato" cannot be hypothesized (Clause 10). In one of our SOLAR experiments, the number of obtained hypotheses is 7 when the maximum search depth is set to 10 and the maximum length of produced clauses is 4. One plausible hypothesis is:

print_connected_by_analogy(spiccato, support_bow_with_ringfinger) ∧
similar(support_bow_with_ringfinger, shock_absorber)

which indicates that the support of the bow with the ring finger in spiccato is analogous to the shock absorber in the forced vibration as shown in Figure 2.

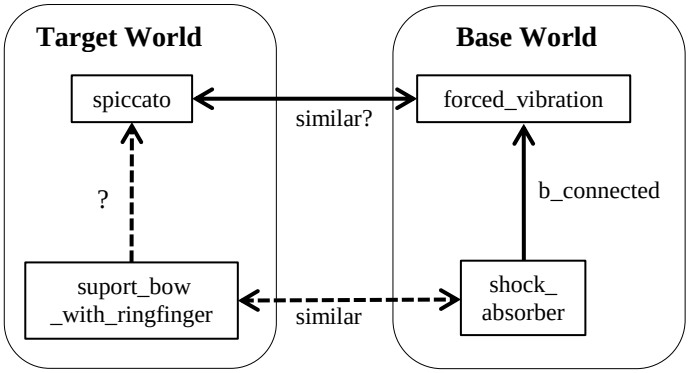

Figure 2. Analogical abduction for achieving spiccato playing.
The dotted lines are to be computed as a hypothesis.

4.3.2 Interpreting a newly invented predicate by analogy

In this subsection, we consider the problem of showing the effectiveness of bending the thumb to achieve the quick crossing of strings (cross strings quick). We use the skeletal structural linkage of the knuckle (of the first four fingers) and the thumb (b_ connected(knuckle, thumb)) as a counterpart of a functional linkage of bending the knuckle and bending the thumb (t connected(knuckle bend, thumb bend)) in the analogy setting. Note that we define the similarity only between "bending thumb" and "thumb" without providing the predicate "bend knuckle", which is to be invented by abductive reasoning. In this example, we discover missing similarities and invent a predicate at the same time. The problem structure is shown in Figure 3.

The abduction program for this problem is shown as follows (axiom clauses are omitted here):

```
% Observation(G) :
t_caused(cross_strings_quick, bend_thumb).
% Abducible predicates( Γ ) :
abducibles([connected_by_abduction/2, similar/2,print_connected_by_analogy/2]).
% Background Knowledge(B) :
%%% Base world:
b_connected(knuckle, thumb),
%%% Target world:
:-connected_by_abduction(cross_strings_quick, bend thumb).
% Similarity:
similar(bend_thumb, thumb).
```

Under the same condition as before, we obtained 7 hypotheses, one of which is the following:

connected_by_abduction(cross strings quick, X) ∧
similar(X, knuckle) ∧
print_connected_by_analogy(X, bend thumb)

This hypothesis accurately represents the structure shown in Figure 3. We further conducted our experimental study by deleting the similarity relation "similar(bend_thumb, thumb)" from the above program and then succeeded in recovering this link as well.

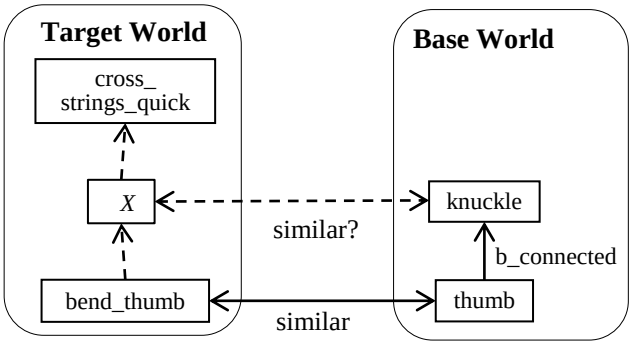

Figure 3. Analogical abduction with predicate invention. A predicate *X* is introduced by abduction in Target World. An analogical reasoning is conducted to give an interpretation of *X* as similar to "knuckle" in the Base World.

4.4 Explaining the Effectiveness of Metaphorical Expression

To show the applicability of our approach to different kinds of problems other than mechanical models, we apply our analogical abduction to explain the effectiveness of a metaphorical expression. An example of metaphorical expression,

issued by a trainer to achieve forte-piano dynamics in orchestra rehearsal, is "eating pancake on the sly," which means that one takes a big mouthful of pancake first, and then he/she tries to make it secret by a motion of imperceptible action of chewing. The difficulty of achieving such dynamics arises because we cannot control our muscle strength accurately because of an inability to precisely estimate force. In addition, it is quite difficult to attain consensus amongst players about the shape of the dynamics envelope. But a metaphorical expression can sometimes help achieve a consensus. This phenomenon is formalized in terms of our analogical abduction framework. Our goal is to prove "t_caused(forte_piano, eat_pancake_on _the_sly)". We assume that the expression "eating pancake on the sly" induces a sequence of motor control commands indicating a big action followed by an imperceptible action in the brain, which arises within the metaphorical base world (see Figure 4). The analogical abductive reasoning is shown as follows:

% Observation(G) :
t_caused(forte piano; eat pancake on the sly).
% Abducible predicates(Γ) :
abducibles([connected by abduction/2, similar/2, print_connected_by_analogy/2]).
% Background Knowledge(B) :
%%% Base world:
b_connected(big_then_impercep_action, eat pancake on the sly).
%%% Target world:
:-connected_by_abduction(forte_piano, eat_pancake_on_the_sly).

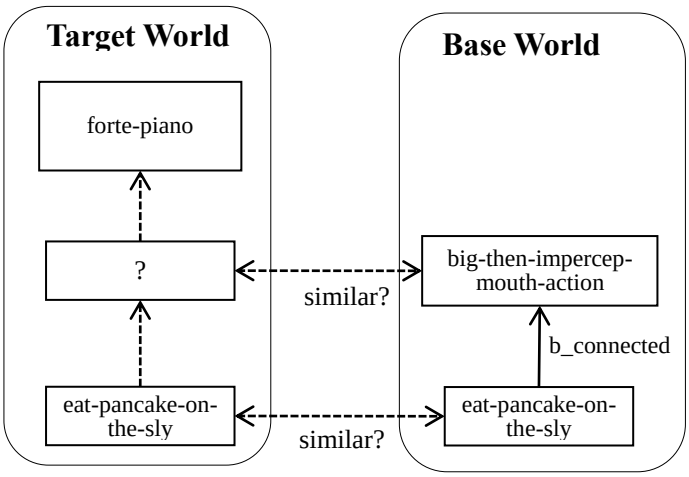

Figure 4. Mataphorical expression of "eating pancake on the sly" to achieve forte-piano.

Under the same condition as before, we obtained 6 hypotheses, one of which is the following:

connected_by_abduction(forte_piano, X) ∧
similar(X, big_then_impercep_action) ∧
similar(eat_pancake_on_the_sly, eat_pancake_on_the_sly) ∧
print connected by analogy(X, eat_pancake_on_the_sly)

Note that the third atom has the form "similar(X,X)". Namely we regard the same thing as similar.

The entire problem structure of this analogical abduction is almost the same as our previous predicate invention example shown in Figure 3 except for the treatment of the similarity relation at the bottom; it is abduced in the metaphorical analogy case whereas it is given from the beginning in Figure 3. The key characteristics of the metaphorical analogy is that the same analogical expression appears in both the base and the target worlds. Since a metaphorical expression directly induces an emotional feeling to encourage the production of adequate motor control commands for achieving the given goal, it should be included in the target world. Alternatively, the same metaphorical expression triggers a similar motion in the eating action which means that it should be in the base world. Another remark is that the metaphorical expression of "eating pancake on the sly" plays the role of converting a quantitative direction of the sound volume adjustment into a qualitative one, which is much more intuitive and understandable.

5. Other possibilities for Explaining Knack

In the last section, we showed the usefulness of analogical abduction as a promising way to produce persuasive explanative arguments for understanding the reason why the given knacks work well in performing difficult tasks. Abduction finds the location of missing links in the proof tree and analogy gives interpretation of the found links including both a causal link and a newly introduced predicate.

This chapter discusses other possibilities for explaining the idea of a knack. For example, while studying the one-bow staccato technique, we found the importance of holding the bow while stretching the thumb contrary to ordinal bow-holding. In fact, this knack is very useful in increasing the bow stability during the one-bow staccato performance. However, this consequence was not understood easily by the learners before observing a performance video showing virtuoso technique of the one-bow staccato. By looking the video, most of the learners suddenly understood the role of the new bow-holding way which can be expressed as pinching by the thumb and other fingers. This experience supports the usefulness of observing skillful videos to understand the key points of the knack.

Another experience supports the importance of metaphorical expression for delivering a sense of musicality in ensemble performance. We introduced the example metaphorical expression "eating pancake on the sly," where we claimed that

such an expression sometimes helps achieve a consensus among players. Precisely speaking, this situation is not a knack explaining problem. However it provides all the players a common musical feature how to play the given note having the "forte-piano" sign. Therefore it is a musicality explaining problem which is closely related to knack explaining. Furthermore, we succeeded in formulating this "forte-piano" expression problem in terms of our analogical abduction framework.

6. Discussion and Future work

We have discussed the feasibility of our analogical abduction in skill acquisition. In acquiring skills, we need to understand adequate knacks to achieve given difficult performance tasks like spiccato or rapid cross strings of bow movement in cello playing. There are two kinds of activities required to obtain such knacks: to encounter such knacks and to assimilate and/or accommodate them to their own knowledge. The problem of encountering knacks is achieved in various ways: being taught by teachers, by watching good performance, by trial and error by themselves and so on. A possible scientific support for this encountering is physical meta cognition [3,4]. In this paper, we focused on the accommodation aspect in knack acquisition. We discussed the importance of knack explanation to achieve the accommodation problem. Analogical abduction plays an essential role in this mental processes, since we need a precise explanation why a given knack is useful in achieving the given performance task. Analogical abduction gives an explanatory argument to achieve a task by showing the validity of the knack as a proof in causality links and analogical arguments.

There is another fundamental issue to be addressed to achieve more realistic analogical abduction. In this paper, we explicitly provide a base world analogous to the target world. In real problems for discovering or explaining skills, we may need to find an appropriate base world itself, before being able to conduct analogical reasoning, or to find and extract similar sub-worlds adequate for analogical abduction from the given target and base worlds. To deal with these problems, we have to provide detailed attributes to the components of each world and compute the degree of similarity for each pair of subset to find analogous pairs [14].

In our approach, we put an abduction engine in the center and tried to add analogical reasoning on top. However, there are other possibilities to generalize our approach further to find better integration of abduction and analogy, including metaphor. One viewpoint is to make analogical reasoning propose adequate abducibles for abduction. This should by realized by strengthening abductive reasoning engine by adding the feature of automatic preparation of abducibles supported by analogical reasoning. Another viewpoint is to use abduction to propose appropriate similarity relations to establish analogical reasoning, which has been reported here. In other words, abduction and analogy are supporting each other. An ideal implementation of a complementary abduction-analogy system is future research work.

Finally, we notice the importance of ML representation of causality and analogical reasoning. At first, we introduced the ML representation to realize rule abduction. Later we succeeded in realizing analogical reasoning by adding an analogy axiom with the predicate "*connected_by_analogy*(*X, Y*)" as well as the similarity predicate "similar(*X, Y*)". Note that both predicates are meta predicates both of whose arguments are propositions. In a sense, the ML representation made it possible to concisely augment the functionality of analogical reasoning to our rule abduction system. It is interesting to note that rule abduction and analogical reasoning are important aspects of human cognitive functions. This leads an important suggestion that ML representation may work as a key role in human thinking. The handling of metaphor is another evidence of this conjecture. There are remaining researches to promote this idea further.

Acknowledgement

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The Trend in the Frontal Area Activity Shift with Embodied Knowledge Acquisition

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Abstract. This paper discusses the relationship between brain activity and repeatability of actions during the process of embodied knowledge acquisition. Subjects watched a video clip of a working procedure and executed the same series of actions. We conducted the same experiments twice. After the first experiment, we set up three practice trials. In the observation task, the trend in oxy-hemoglobin levels shifted toward a low-level increase in the dorsolateral prefrontal area and a low-level decrease in the frontal lobe with improvement in performing the skill. In the execution task, the trend in oxy-hemoglobin shifted toward an increase in the dorsolateral prefrontal area and toward a decrease in the frontal pole with improvement in performing the skill. These results suggest that activities in the frontal area shift during the process of embodied knowledge acquisition.

Keywords: Body Intelligence, Brain Activity, Near-Infrared Spectroscopy, Knowledge Acquisition

1 Introduction

Explicit knowledge can be expressed as text, figures, tables, etc. On the other hand, knowledge that is not easily expressed is called tacit knowledge [1, 2]. In this study, we define tacit knowledge to include embodied knowledge, which is a set of skills based on experiences and intuitive sense as seen in performing an art, sport, craft, or other skilled task. Embodied knowledge cannot be easily communicated and shared because of the difficulty in evincive expression. For this reason, both the learner's and instructor's efforts are important for acquisition of embodied knowledge.

In core manufacturing industries, embodied knowledge includes skills pertinent to making products, and effective sharing of knowledge is an important issue for developing human resources. Instructors with a lot of embodied knowledge can provide advice to learners regarding the quality of their work and products. However, from a prac-

tical standpoint, ensuring that instructors have the time to practice with learners is difficult [3]. In addition, because of the difficulty in evincive expression, the learner's level of embodied knowledge is difficult to evaluate. An example of a method to evaluate the level is a practical exam taken by the learner. Exam monitors need to be experts in the skill, and they evaluate the learner's level based their experiences. Due to the nature of embodied knowledge and the reality regarding the practical work site, learners need to objectively evaluate their own level of embodied knowledge to acquire the knowledge on their own. Acquiring embodied knowledge involves high levels of information manipulation such as internalization of tacit knowledge. Measuring brain activity is an appropriate method for objective evaluation of the level of internalization.

Thus, we used near-infrared spectroscopy (NIRS) to investigate the relationship between brain activity and embodied knowledge during the process of embodied knowledge acquisition. Evaluation of the level of knowledge acquisition with monitoring of brain activity can be an objective indicator of the learner's degree of skill progression. Evaluation of the learner's degree of acquisition enables one to predict improvement with modeling and to present options for more effective methods of learning. Therefore, our final goal is constructing a new learning model and improving learning efficient by the learning model via brain science.

During the process of embodied knowledge acquisition in core manufacturing industries, it is essential to remember the operation procedures of the process machinery. In this paper, we targeted procedural memory and imitation learning and investigated the relationship between brain activity and repeatability of actions.

2 Measurement of frontal area activity by NIRS

2.1 Optical brain imaging system

When neural activity occurs in the brain, blood flow increases in the tissue near the active neurons, and the rate of oxygenated and deoxygenated hemoglobin (oxyHb, deoxyHb) in the blood changes. Near-infrared light (700-900 nm) is harmlessly transmitted through the human body, and hemoglobin characteristically changes following near-infrared absorbance, depending on the oxygen level in the hemoglobin. These properties enable non-invasive measurement of brain activities. Another advantage of NIRS is that it allows subjects to move, unlike other brain function measurement techniques. NIRS has relatively high spatial resolution, and the NIRS device is small and portable. Thus, in this study of the process of learning embodied knowledge, NIRS is a valid measurement technique.

2.2 Measurement of the frontal area and removal of artifact due to biofunction

The dorsolateral prefrontal area is closely related to working memory, as it establishes long-term memory [4]. The ability to later remember a verbal experience is predicted by the amplitude of activation in the left prefrontal and temporal cortices during that experience [5]. In a previous experiment we conducted, in which the subject remembered a set of simple body actions by imitation learning followed by execution, the

oxyHb level increased in the dorsolateral prefrontal area and decreased in the frontal pole [6]. Thus, we measured activities in the frontal lobe and analyzed the same areas including the right prefrontal area (Channel 20), frontal pole (Channel 23), and left prefrontal area (Channel 26) (Fig. 1).

In NIRS, optical fibers are placed on the scalp of the subject based on the international 10-20 system. Because of the fibers and scalp contacts, the measurements are affected by the subject's body motion, metabolism, and breathing. Thus, assuming that such artifacts are similar in all brain regions, we employed global average references [7]. In this article, the effectiveness of the global average references was verified using NIRS for static tasks such as listening to music, reading text, solving puzzles, or other static tasks. However, global average references were applied assuming that artifacts are similar in all brain regions, and this hypothesis can be applied to such experiments involving body motion. For each trial, results were standardized to the measurement result at rest before the task (Pre-Rest) with Eq. (1).

$$\Delta\mathrm{oxy}(t)_{Z-SCORE} := \frac{\Delta oxy(t)_{raw} - \mu^{\Delta\mathrm{oxy}}_{pre-rest}}{\sigma^{\Delta oxy}_{pre-rest}} \tag{1}$$

Where Δoxy(t) denotes the measured value of oxyHb at time t on each channel, $\mu^{\Delta\mathrm{oxy}}_{pre-rest}$ is the average oxyHb change in the Pre-Rest time, and $\sigma^{\Delta oxy}_{pre-rest}$ is the standard deviation for the Pre-Rest time. Then, the standardized measurement result was averaged for each of the 32 channels in time. Finally, this result was subtracted from the standardized measurement result at each point with Eq. (2).

$$\Delta oxy(t)_{GR} := \Delta oxy(t)_{Z-SCORE} - \frac{\sum_{l=1}^{n} \Delta oxy_l(t)_{Z-SCORE}}{n} \tag{2}$$

Where n denotes the total number of channels. In this experiment, n is defined as 32 channels, the total number of channels.

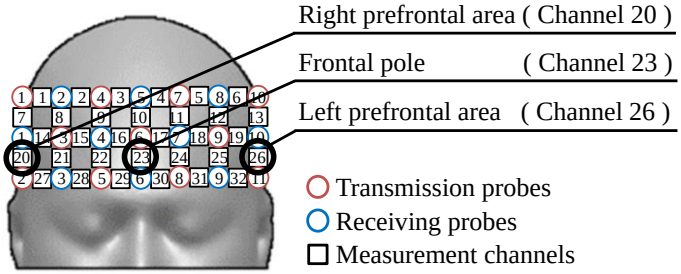

Fig. 1. Region of NIRS measurement

3 Measurement of brain activation during the learning of work procedures

3.1 Imitation learning to form procedural memory simulating skills in industries

Simulating skill acquisition in core manufacturing industries involves acquiring embodied knowledge, which leads to procedural memory of a skill. Subjects remember and execute a set of procedures by imitation learning. The purpose of this experiment was to measure the trends in changes in brain activities with development of a skill by imitation learning.

The subjects were seated at a desk so that they could see a display in front of them (Fig. 2). One experiment was composed of three trials. The portion of the trial during which the subject carried out the experimental task lasted 180 seconds, and the rest time before and after the task lasted 30 seconds. This trial was executed three times by each subject. Instructions for the task were shown on the display for 5 seconds after the task started, and the instructions ended 5 seconds before the task ended. During the rest time, the subject was told to rest without thinking. In the first trial, the subject rested throughout the trial (the rest trial). In the second trial, the subject observed and remembered a set of procedures shown in the display, which was a video clip of assembly work (the observation trial). The assembly work lasted 157 seconds, and then the clip of the finished product lasted 13 seconds. The parts for assembly were placed on the desk after the trial. In the third trial, the subject executed the procedures that he remembered in the observation trial (the execution trial). The end of the task was indicated on the display, and the subject signaled with a buzzer only in the execution trial. Before the experiment, the experimental structure and instructions to remember the procedures as distinct from the finished product were explained to the subject. To carefully handle the assembly parts, subjects assumed a bent forward posture. The subjects were instructed to maintain the bent forward posture, because changes in position cause artifacts. The subjects were five healthy men in their early twenties (A, B, C, D, E) who provided consent for participation in the experiment. The experiment ran for 2 days (Table 1), and the subject practiced the tasks without undergoing NIRS to improve the skill. The subject performed the observation task and the execution task after measurement on the first day, and then performed these tasks two times in a row before measurement on the second day.

3.2 Repeatability of the remembered procedures

We evaluated the procedures that each subject executed in the trial for repeatability, which indicates the degree of imitation. In general, an expert in the skill determines the skill level. However, in this experiment, we objectively determined the skill level due to limited skills in the procedures for the assembly work. Therefore, the procedures were broken down into 12 numerically ordered steps and scored by an additional method. If the number of the executed procedure was higher than that of the previous procedure, one point was scored. This method allowed a score of up to 11 points. Asymmetrical shapes and colors of the assembly parts were distinguished.
Evaluation of the procedures is shown in Table 2. Each subject scored low, around 0 to 2 points, on the first day that the subject was instructed to perform the assembly work. On the second day, all subjects scored 10 points. This result suggests that all subjects improved their skills during the trials.

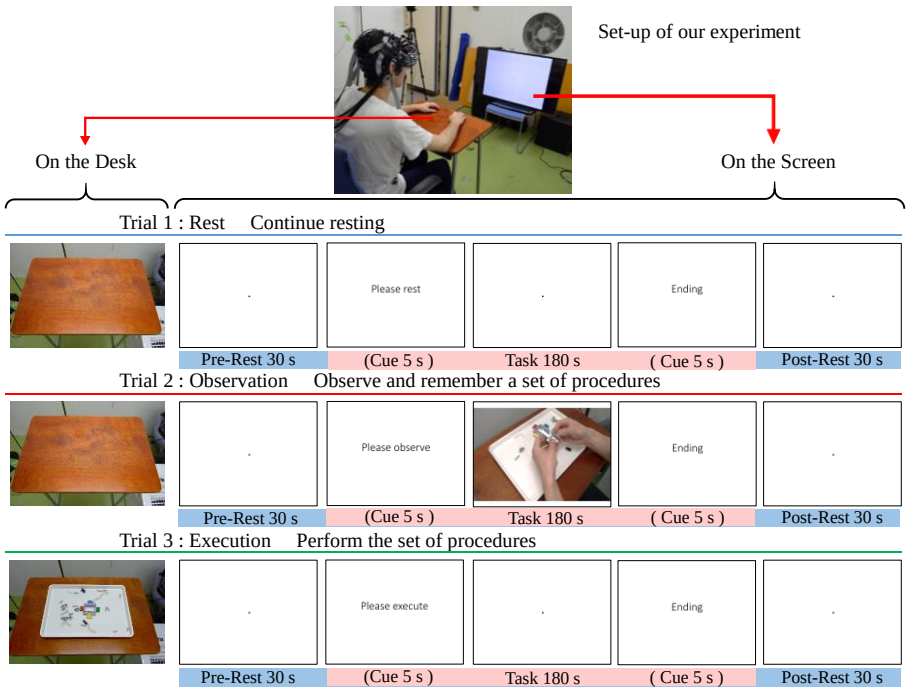

Fig. 2. Experimental design

Table 1. Experimental schedule. The numbers indicate the subject's accumulated performance counts.

	First day		Second day		
	Measure-ment	After measurement	Before measurement	Before measurement	Measure-ment
Task 1 Rest	1	-	-	-	2
Task 2 Observation	1	2	3	4	5
Task 3 Execution	1	2	3	4	5

Table 2. Results of the execution procedure

Subjects		The execution procedures (The numbers indicate the number of procedures)												Total
A	First day	1	4	2	-	-	-	-	-	-	-	-	-	1
	Second day	1	2	3	4	5	6	7	9	10	11	12	-	10
B	First day	2	1	-	-	-	-	-	-	-	-	-	-	0
	Second day	1	2	3	4	5	6	7	9	10	11	12	-	10
C	First day	1	4	2	-	-	-	-	-	-	-	-	-	1
	Second day	1	2	3	4	6	7	8	9	10	11	5	12	10
D	First day	1	2	4	-	-	-	-	-	-	-	-	-	2
	Second day	1	2	3	4	5	6	7	8	9	10	11	-	10
E	First day	2	-	-	-	-	-	-	-	-	-	-	-	0
	Second day	1	2	3	4	5	6	7	8	10	9	11	12	10

3.3 The Relationship between Brain Activity and Repeatability of Actions during the Process of Embodied Knowledge Acquisition

The result of oxyHb in the rest trial was compared with that in the observation trial (Fig. 3). The oxyHb in the rest trial was stable at low levels on both days. The oxyHb in the observation trial increased in Channels 20 and 26 and decreased in Channel 23. These tendencies stabilized at a low level, and the confidence interval of the oxyHb narrowed on the second day. The outcomes indicate that the frontal area activities during formation of procedural memory by imitation learning tended to stabilize at a low level due to practice. One explanation for this may be that practice resulted in a reduced amount of information to remember from the video clip and that frontal area activities shifted to a similar tendency as in the rest trial.

The result of oxyHb in the rest trial was compared with that in the execution trial (Fig. 4). The oxyHb in the rest trial was the same as in Fig. 3. The result on the first day

showed a similar tendency as the oxyHb in the rest trial. The oxyHb in the execution trial increased in Channels 20 and 26 and decreased in Channel 23. The differences in Channels 23 and 26 on the second day were significant. The outcomes indicate that the trend in frontal area activities during the execution of remembered procedures is amplified due to practice. The subject had more information about the assembly work on the second day, and this increase was related to the function of retrieving the memory, executing the remembered procedures, or both.

Comparing the results on the first day with the second day, repeatability was improved by imitation learning, which may increase skill levels. Limited acquisition of embodied knowledge due to procedural memory produced an increase in the oxyHb level in Channels 20 and 26 and a decrease in Channel 23 in the observation trial during the early stage. The tendencies were mitigated due to a reduction in the amount of information to remember. In the execution trial, oxyHb did not show a trend that depended on the task during the stage. The increase in oxyHb in Channels 20 and 26 and the decrease in Channel 23 were due to an increased amount of information to execute.

We compared the summed total amounts of the adjusted oxyHb levels during the task period in each subject on the first day with the second day to focus on the change in the trend (Fig. 5). The total amounts in the rest trial were low on both days. The amounts in the observation trial showed positive high levels in Channels 20 and 26 and a high negative level in Channel 23, and these shifted to a lower level. The amounts in the execution trial were low in the three channels and shifted to positive high levels in Channels 20 and 26 and a high negative level in Channel 23.

These outcomes suggest that frontal area activities shift during embodied knowledge acquisition, improving assembly work. Assuming these activity shifts are applicable to more high-level skills, we can predict a degree of improvement based on brain activities.

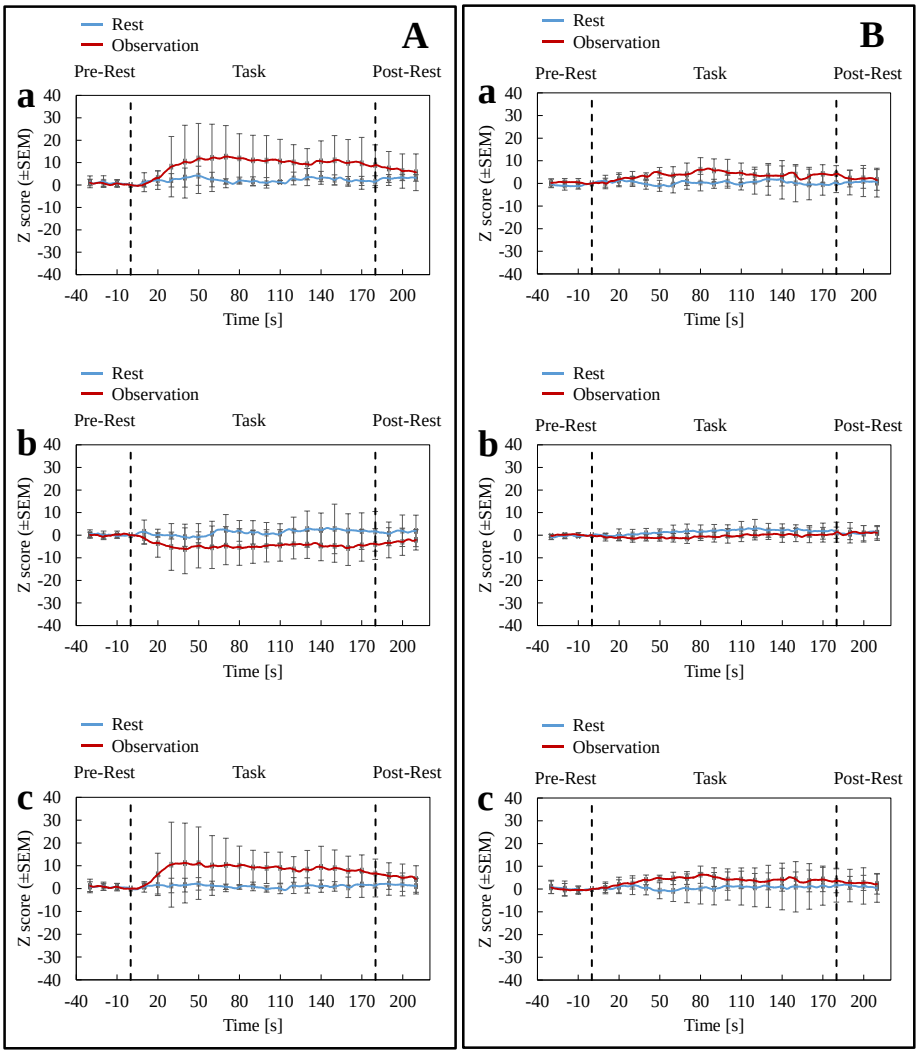

Fig. 3. Comparison of mean oxyHb variation in the observation trial with the rest trial ($P < 0.05$). (A) First day. (B) Second day. (a) The right dorsolateral prefrontal area (Channel 20). (b) The frontal pole (Channel 23). (c) The left dorsolateral prefrontal area (Channel 26).

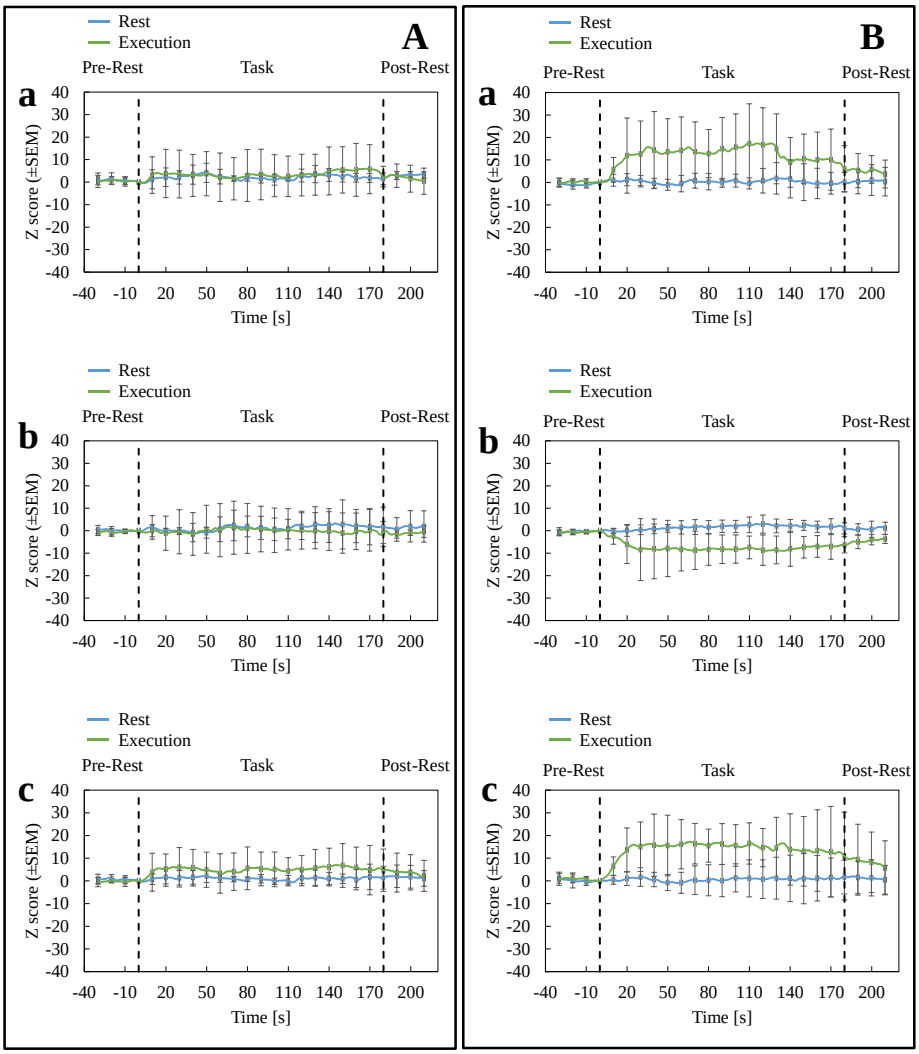

Fig. 4. Comparison of mean oxyHb variation in the execution trial with the rest trial ($P < 0.05$). (A) First day. (B) Second day. (a) The right dorsolateral prefrontal area (Channel 20). (b) The frontal pole (Channel 23). (c) The left dorsolateral prefrontal area (Channel 26).

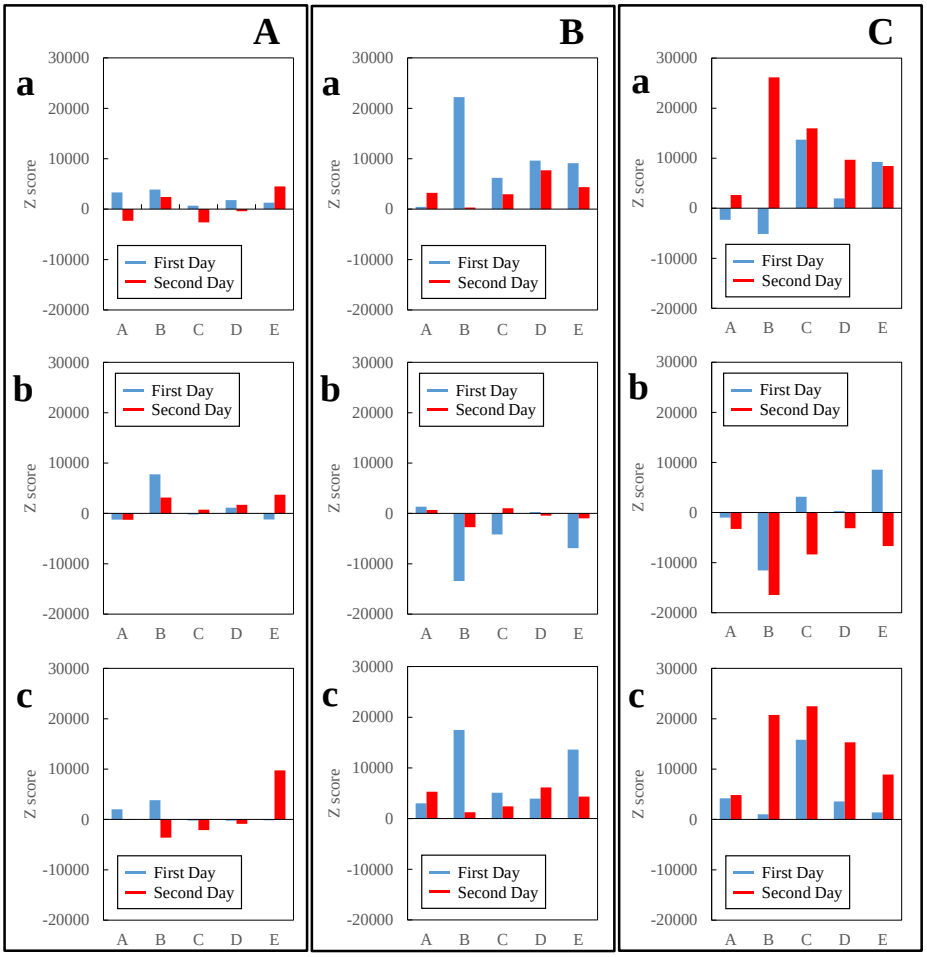

Fig. 5. Comparison of the total oxyHb during the task period on the first day with the second day. (A) The rest trial. (B) The observation trial. (C) The execution trial. (a) The right dorsolateral prefrontal area (Channel 20). (b) The frontal pole (Channel 23). (c) The left dorsolateral prefrontal area (Channel 26).

4 Conclusion

In this paper, by limiting acquisition of procedural memory through imitation learning, we analyzed the relationship between brain activity and repeatability of actions during the process of embodied knowledge acquisition. With low repeatability, the oxyHb level increased in the right and left dorsolateral prefrontal areas and decreased in the frontal pole during the process of observing and remembering the procedures. The level stabilized to a level similar to that in the rest trial during execution of the task. With high repeatability during observing and remembering, the oxyHb level stabilized to a level similar to the level during rest. The oxyHb level increased in the right and left dorsolateral prefrontal areas and decreased in the frontal pole during the process of execution. These outcomes suggest that the frontal area activities shift during embodied knowledge acquisition. In the future, we intend to perform more long-term experiments and reliable analyses by increasing the number of subjects and changing the tasks. Additionally, although analytical methods can be used to reduce the effect of the subject's body motion, an experimental method that separates brain activities elicited by a task from the effect of body motions is needed.

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Identifying Context-dependent Modes of Reading

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Abstract. Reading time is commonly used as a basis for the study of reading. It has been observed in previous studies that unexpected sentences initiating a new context in a body of text considerably increases its reading time. There are two general accounts of the mechanism behind this slowdown. The first views reading, both slow and fast, to be a single, continuous process. The second views reading as consisting of multiple, distinct modes of processing. We consider in this paper the problem of distinguishing between these two accounts. To do so, we present a new kind of statistical analysis of data obtained from two different experiments on reading time. Our analysis supports the two-mode account of reading slowdown.

Keywords: Reading; Comprehension; Gamma Distribution

1 Introduction

Reading has been studied in various levels of cognitive processes, such as word identification, syntactic parsing, discourse processing [12]. At the levels of the comprehending narratives such as novels, readers have rich experiences; in the beginning they imagine the characters and the world, then devoutly read page after page with fun, and catch their breath at the unexpected unfoldment.

Past studies have focused to discuss the reading of shorter and controlled stories, and more rapid processing of reading than those broad changes with the contexts of literary works as described above. In those studies, reading time has been used to identify factors which may affect reading processes[8, 15, 4]. It has been reported that reading slows down considerably at the beginning of a clause, sentence, paragraph, or story – constructs which indicate a change in context – and subsequently speeds up again [1, and see also Gernsbacher (1997) for the

* Please note that the LNCS Editorial assumes that all authors have used the western naming convention, with given names preceding surnames. This determines the structure of the names in the running heads and the author index.

review]. These findings have been interpreted using theoretical models of reading processes.

For example, Gernsbacher(1990)[3] have proposed the *Structure building framework* which suggests that reading involves three component process - *foundation-laying*, *mapping*, and *shifting*. Foundation-laying is the first process of comprehension and in which readers lay a foundation for their mental structure. When the incoming information is consistent with previous information, readers *mapping* the new information onto their foundation. When there are inconsistencies between the incoming information and the existing information, readers *shift* and build a new structure.

In this study, we are interested in readers' cognitive processes during reading longer and real literary works. The question is whether readers' reading processes changes with contexts of stories in a qualitative manner, like *Structure building framework*, instead of only their speed. We also analyzed the reading time, but developed a statistical technique discussed in 1.1 which allows us to detect qualitative differences of cognitive processes depended on the contexts of these stories.

1.1 Statistical analysis of reading time

We assume the reading processes are composed of several subprocesses, and we call such qualitatively distinct collection of subprocesses involved in reading a *reading mode*. Then different collection of subprocess are regarded as different mode in this definition.

The question is, given reading data, how we can infer the number of reading modes reflected in the data? In the previous studies about short texts and more rapid processes, differences in reading time alone have been interpreted as reflection of two qualitatively distinct processes [2]. However, reading time may vary depending on multiple factors like frequency, familiarity, and the lengths of words [7, 14]. We cannot, therefore, naively interpret reading time alone as an indicator of multiple reading modes.

This observation motivates the development of new analysis technique for reading time. The analysis we present as an alternative is based on a statistical theory of processing time [6]. In this theory, the presence of multiple different modes of processing can be detected by the statistical distribution of the processing time.

If the reading process consisted of n subprocesses with the same constant processing rate over time, in other words the process finished only when all these subprocesses have finished, the reading time would follow a gamma distribution with shape parameter n (Figure 1 (a)). If, on the other hand, the reading process consisted of one subprocess with process rate t^k as a function of the process time t, in other words the process finished when at least one subprocess has finished, reading time would follow a Weibull distribution with shape parameter k (Figure 1 (b)).

Setting $n = 1$ in a gamma distribution or $k = 1$ in a Weibull distribution yields an exponential distribution. There is, therefore, a statistical relationship

between the types of distributions that processing time follows even as the number of Poisson processes involved with process vary.

This statistical analysis allows us to distinguish processes which have a same average speed of processes but have different number of subprocesses (Figure 2, A and B), and to distinguish processes which have same number of subprocesses but have different average speed of processes. This subprocess estimation gives an advantage over the previous studies analyzing differences in the reading time alone.

We adopt this statistical account of processing time in evaluating the number of reading modes based on reading time. If each observation in a reading time dataset follows essentially the same distribution as the others, we would treat this as an indicator of a single reading mode. If, on the other hand, the data set appears to have been generated by sampling from a mixture of distributions, we treat it as an indicator of multiple reading modes (Figure 3). Each dataset in question is composed of observations about a single subject. This technique therefore removes overall reading speed as a factor in the analysis.

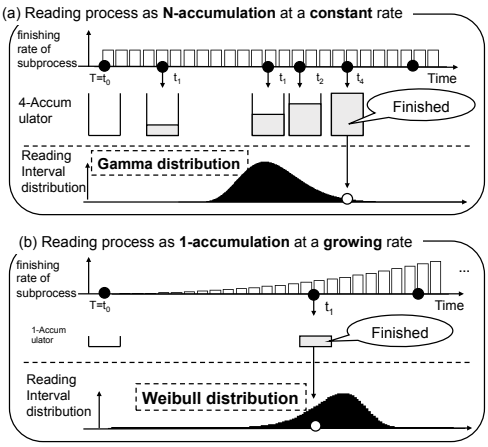

Fig. 1. Schematic illustration of the different types of reading processes and corresponding statistical distributions.

1.2 Approach

When reading, one is generally also engaged in many other processes – eye movements, posture management, etc. If one were only lightly engaged in reading and more heavily preoccupied with a number of these other activities, it is entirely possible that their preoccupation could appear as distinct reading modes in our statistical analysis. To prevent the detection of such false modes, it would be valuable to have a measure of reading engagement independent from reading time. We could then test the results of our statistical analysis based on their correlation with that measure.

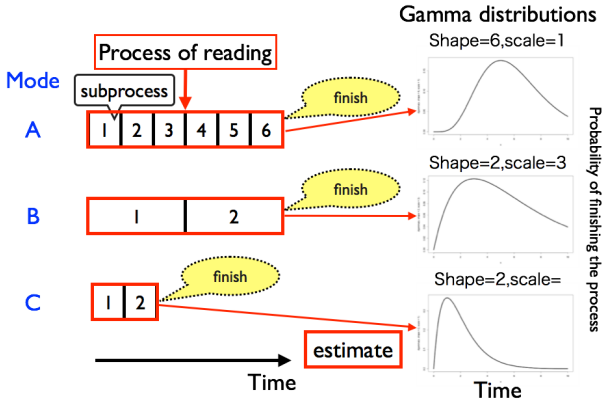

Fig. 2. Processes which have different numbers of subprocess and average speeds are estimated different distributions. These examples illustrate the processes which finish only when all subprocesses are finished. Mode A: 6 subprocesses, each takes short time on average, Mode B: 2 subprocesses, each takes long time, Mode C: 2 subprocesses, each takes short time. The overall average of both Mode A and B is the same, but their distributions (on the right hand side of the figure) are different.

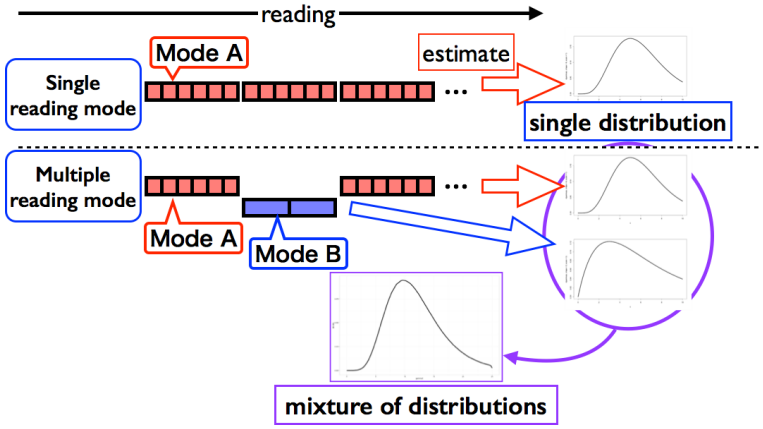

Fig. 3. (top) A single reading mode is repeated across multiple pages results in a single gamma distribution.
(bottom) Two reading modes, A and B, appear across different pages result in mixture of two gamma distributions.

Since the analytic technique we will use is statistical in nature, it requires relatively large datasets in order to produce meaningful results. To this end, and although this is not typical of existing studies of reading, we use entire novels as the texts in our experiments.

Given the burden that reading such long texts places on the subjects of our experiments, our first experiment consisted of only one subject – Miho Fuyama, the first author of this paper. She is an avid reader, which suggests that she is generally easily engaged in reading as an activity. In Experiment 1, we studied her reading time and the degree of engagement in reading across two books in order to empirically establish the validity of our analysis. We then analyzed data generated during her readings of 18 additional novels in order to test whether her reading process has a single or multiple reading modes.

Having validated our statistical analysis, we adopted it in our second experiment to a cross sectional study of multiple subjects. In Experiment 2, we asked 5 subjects to read a short novel. The subjects were also asked to evaluate their degrees of reading engagement each two pages after the reading session. This experiment was designed to evaluate whether our findings from Experiment 1 hold in general. We also evaluated changes in reading modes could be related to the semantic structure of the text itself. To do so, we analyze the consistency of the dynamics governing the change of reading modes across subjects and treat the consistent dynamics as text-specific semantic effects in reading.

2 Experiment 1

The first author was the sole subject of several high-load reading tasks. We asked her to read 20 Japanese novels. Each session tool one day including breaks. The set of samples from these 20 sessions of 20 novels was submitted to statistical analysis using the scheme described in the previous section, and we estimated the statistical distribution of her reading time for each two pages. For two of the novels (novels 17 and 18 in Table 1), she evaluated her degrees of absorption each two pages as an indicator of her engagement to reading. Specifically we asked her how absorbed she was in reading every pair of pages in these novels. These absorption ratings were used to validate the statistical analysis.

2.1 Participant

The subject was the first author, Miho Fuyama, who was 30 years old when the experiment was conducted. She is a native Japanese speaker, is a regular reader, and has normal vision.

2.2 Material

We used 20 Japanese novels, which the first author read for the first time in this experiment. The titles, authors, and page lengths of books are listed in Table 1. We selected as texts books witten by authors who have won Japan's prestigious literature prizes, such as the Naoki Prize or Akutagawa Prize.

Table 1. The novels read in Experiment 1.

No.	Title (Abbreviated)	Author	Page length
1	Shikisai	H. Murakami	370
2	Kamisama	H. Mori	314
3	Nameraka	H. Kawakami	189
4	Tenchi	T. Ubukata	474
5	Chinmoku	Y. Ogawa	308
6	Hikari	S. Miura	297
7	Kuchi	M. Banto	309
8	Mizuumi	B. Yashimoto	206
9	Kogoeru	A. Shino	401
10	Self-Reference	T. Enjo	308
11	Shi no izumi	H, Minagawa	427
12	Kisetsu no kioku	K. Hosaka	316
13	Eien no deguchi	E. Mori	313
14	Hokanaranu hito he	K. Shiraishi	295
15	Shorou tomurai dou	N. Kyogoku	498
16	Kodoku no utagoe	A, Tendo	312
17	Neko	Y. Ogawa	359
18	Ruto 225	C. Fujino	282
19	Yasashii uttae	Y. Ogawa	260
20	Burahuman	Y. Ogawa	146

2.3 Procedure

In each session of the experiment, the subject was asked to read a novel. Each session lasted several hours (including breaks), but was completed in one day. The subject reported her degrees of absorption for every two pages read in novels number 17 and 18. These reports were made approximately 100 days after the reading sessions. Her degree of absorption was measured on a five-level scale – "extremely bored", "bored", "normal", "absorbed", and "deeply absorbed". This scale was coded using the numbers $-2, -1, 0, 1$, and 2 respectively for each of the states. As the experiment required her to focus on and to become absorbed in such long texts, the subject was allowed to perform her readings at her home in order to minimize her tension. She was also allowed to have breaks whenever she wanted. The breaks were typically 5 to 15 minutes long, but there were also several hour-long lunch breaks. While reading, she sat at her desk and was videotaped with two small web cameras.

2.4 Analysis

From the videos, we transcribed the reading time for each pair of pages. These reading times were measured as the lengths of time between page turns, excluding time spent on break. The statistical analysis is performed on these transcribed reading times. We analyzed the aggregate of the data gathered across all

the sessions of the experiment in order to increase the statistical power of our analysis.

In our analysis, we fitted mixtures of exponential distributions, those of Weibull distributions, and those of gamma distributions to the aggregate data. For each mixture distribution, ranging from 1 to 5 components, we estimated the parameters by maximizing likelihood. As these statistical models have different numbers of parameters, we chose the model with the smallest Bayesian Information Criterion statistic [13] as the one which best explains the data.

2.5 Results and discussion

We found that a mixture of two gamma distributions provides the best fit to the aggregate data amongst all the distributions considered. Figure 4 illustrates the differences between these various classes of distributions in explaining our data. It shows the hazard function $H(t)$ of the page-turn interval t. The hazard function $H(t)$ is the conditional probability (density) to finish reading given the reading being unfinited until t. Exponential distributions in general exhibit a constant $H(t)$, which means this random process has "no memory" – a constant rate of reading interval regardless of time. Weibull and gamma distributions, in contrast, have increasing hazard functions. This means that the reading becomes more and more likely to be finished as time goes on. The two class of distributions, however, exhibit differences in the shape of their hazard functions.

The exponential distribution, with a constant hazard function, did not fit the data well in Figure 4 (BIC = 29421.71). Likewise, the Weibull distribution has large deviation from the data at the tails of distribution ($t < 30$ and $140 < t$) (BIC = 26146.06). The single gamma distribution fits better than the exponential and Weibull distributions (BIC = 25722.64), but the mixture of two gamma distributions provides the best fit (BIC = 25655.29). In addition, mixtures of three gamma distributions (BIC = 25677.24) or more did not provide better fits than the two-component gamma distribution.

Figure 5 shows the probability density function of empirical reading intervals and the estimated probability density function, which is a mixture of two gamma distributions. One subcomponent, Distribution 1, has shape 13.80 and scale 4.24. The other subcomponent, Distribution 2, has shape 7.58 and scale 10.67. This result suggests that the subject shows of two distinct modes in her reading, with each mode involving different reading subprocesses. It is worth noting that, at this point, we have not established the relationship between the two statistically estimated modes and the putative cognitive processes for reading.

Correlation to reading engagement We now address the question of whether the two distinct modes identified in our analysis are actually reflective of the text being read. In order to test this, we analyzed the correlation between the temporal change in mode and the degree of absorption reported by the reader. We obtained the reader's post-hoc report on engagement for each two pages of the books No. 17 and 18.

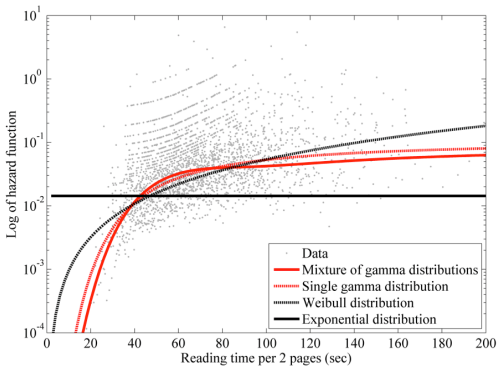

Fig. 4. The hazard function for the sample (dots) and for the estimated probability distributions (lines) of reading time per two pages.

Taking the book No. 17 as a representative case, Figure 6 shows the temporal profile of the weighted-average of shape parameters (black dots) and the reader's degrees of absorption (red dots). The weights was given by the mixture of the two gamma distributions for each reading time of two pages. The corresponding moving average of the two over 5 data points are shown as black and red line, respectively.

We performed correlation analysis for a pair of the estimated shape parameters and the degrees of absorption. For the book No. 17 across 141 pairs of pages, we had correlation -0.284 ($p < 0.001$). For the book No. 18 across 118 pairs of pages, we had correlation -0.283 ($p < 0.01$). This indicates that the temporal changes in the modes identified from our reading time analysis (Figure 6) does indeed reflect changes in reading engagement.

Remember that the shape parameter can be interpreted as the number of subprocesses involved in processing a given text, and the scale parameter can be interpreted simply as inverse of reading speed (Figure 1). Taking this theory into account, we conclude that the two modes estimated in this analysis are likely to represent a fast reading mode (Distribution 1) with a larger number of subprocesses and a slow reading mode (Distribution 2) with a smaller number of subprocesses.

3 Experiment 2

In Experiment 1, our statistical analysis detected two different modes of behavior in the reading data generated by the experiment. We further showed that the change in mode over time had a statistically significant correlation to the levels of engagement with the text reported by the subject. Our goal for Experiment 2 was to establish whether or not these findings are consistent across multiple subjects and, if so, to identify the various factors governing the reading modes detected in Experiment 1. In order to answer these questions, we design a short

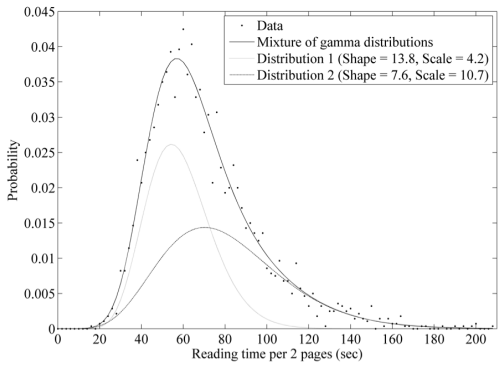

Fig. 5. Sample (dots) and estimated (solid) probability distribution of reading time per two pages. The two curves under the fitting curve shows subcomponents of the gamma mixture distribution.

experiment for the other subjects. In our second experiment, we asked different subjects to read a short novel but kept the rest of the procedure the same as it was in No.17 and No.18 of Experiment 1. Namely, subjects were asked to read a short novel or a part of it, and then they are asked to report their degrees of absorption for each two pages. The novel itself took less than an hour to read.

We expect two possible cases: We may have individual variance in reading time across subjects which would reflect that different subjects exhibited very different ways of processing the text. Second, the reading time may depend on the contextual structure of the text, and different subjects show similar mode changes in reading the same text.

The major factor dictating reading modes would be a subject's reading strategy in the first case. In the second case, it would be the contextual structure of the text itself.

3.1 Participants

In Experiment 2, which is on-going, we employed five participants to read one short story, and employed an additional subject to read another story. As this data collection is on-going, the numbers of participants for the two conditions were not balanced at the moment. The subjects were 4 male and 2 female undergraduate and graduate students at Keio University. Most of these subjects were not regular readers.

3.2 Procedure

The procedure was the same except for the length of the text and the environment in which the reading took place. During each session, one participant read a 49-page long short story in a room reserved specifically for the experiment.

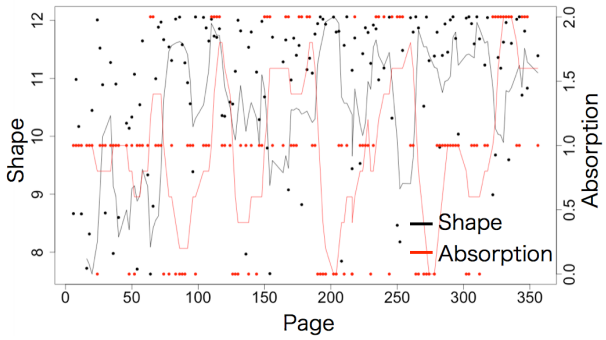

Fig. 6. Page-based temporal profile of the statistical property (shape parameter) of reading time and the absorption ratings of the case No.17.

Right after the reading session, the participant was asked to report their degrees of absorption in the same scale as Experiment 1 for each two pages. The short story they read is entitled "Onna no inai otoko tachi", which was commercially available as part of an omnibus and is authored by Haruki Murakami. In a controlled situation, a sixth participant read a part of another book "Chinmoku Hakubutukan" written by Yoko Ogawa. As the introductory part, from page 3 to 40, of the second book was chosen, this particular text does not include any major change of context. After their reading session, each subject was asked to report his/her degrees of absorption for each two pages using the same five point scale used in Experiment 1.

3.3 Analysis

For consistent comparison, we analyzed the aggregate of the reading time data across subjects by fitting to it a two-component mixture of gamma distributions. We fixed the class of distributions, instead of identifying it from data. This is largely due to the small sample size of our data at this point. Each participant provides reading time data for only 23 pairs of pages, and it did not sufficient statistical power to be conclusive even as its aggregation across subjects. Thus, we employed the statistical distribution estimated in Experiment 1.

3.4 Results and Discussion

Each panel of Figure 7 shows the page-based temporal profile of the modes estimated from reading time. In each panel, a dot shows estimated shape parameter for each reading time data point, and the line indicates its moving average. As in Experiment 1, we found that the temporal changes in modes were significantly correlated to the reported degree of reading engagement ($R = -0.238, p < 0.01$). This result replicates and generalizes the findings of Experiment 1.

Secondly, the result shown in Figure 7 exhibit inter-subject consistency in temporal changes in reading modes. Subjects A, B, C, D, and E read the same text, while subject F read another one. We found a similar inverted U-shape profile in the data of each of the first five subjects, whereas the data generated by subject F did not clearly show a similar pattern.

We performed correlation analysis on each pair of the subjects in order to test whether two groups of subjects have similar temporal profile of shape parameters within the group A, B, C, D, and E and dissimilar with the subject F. The average of correlations between pairs of subjects A, B, C, D, and E was 0.647 ($p < 0.01$), but the average correlations between subject F and the other subjects was 0.040 ($p > 0.693$).

As smaller shape and larger scale parameters suggest that fewer but slow subprocesses are involved in reading a text, high probability of this reading mode in the beginning of reading supports the structure-building account. In addition, this particular story has a "twist" about two-thirds of the way in. This twist is apparent in the upward trend of the probabilities in the first five panels of Figure 7. Our interpretation of this trend is that it reflects the structure-building which is like the *Structure building framework's laying a foundation* or *shifting* taking place due to the sudden contextual change in the storyline.

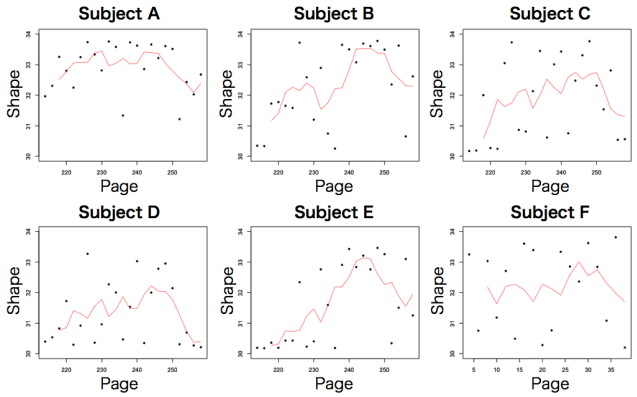

Fig. 7. The page-based temporal profile of the estimated shape parameters for each subject.

4 General Discussion

Reading is an essentially mental and subjective experience. Its cognitive underpinnings have been difficult to characterize directly, and reading time is a major tool for drawing inferences about the underlying cognitive mechanism behind reading. This study offers a new approach to the analysis of reading time, an

approach capable of identifying different modes of reading behavior from reading time data.

In Experiment 1, we collected an analyzed reading time data generated by a single subject reading several full novels in a natural situation. We observed significant correlation between subject's report of her engagement in reading and her reading modes inferred from the estimated reading time distribution. This experiment has three major implications:

1. In contrast to conventional studies on controlled, short readings, it is perhaps the first study on involving reading entire books in a more natural situation.
2. It establishes a new analytical technique for reading time data by associating the estimated modes with the subject's engagement in reading.
3. It provides evidence in favor of theroretical models which assume the existence of qualitatively distinct reading modes.

A clear limitation of Experiment 1 is that we could not employ many subjects due to the intense nature of the experiment. In Experiment 2, each session was designed to be as minimally demanding as possible. This allowed us to perform the experiment using a number of different subjects. We once again observed two distinct reading modes, and found that the mode switches across different subjects reading the same story were consistent with each other. This suggests that, to a large extent, the reading modes are dictated by the contextual structure of the text being read.

In the context of past discussions of reading, the implications of our findings may be related to the issue of *global coherence* in text, which is supposedly necessary to comprehend a text as a whole [8, 5]. In contrast to local inference on the level of words and sentences, global coherence refers to context- level smoothness over long passages which facilitates updates to textual knowledge and incorporating such knowledge with existing common knowledge [11]. Although there are a few experimental findings on global coherence using short texts [9], there is no well-established method of evaluating the global coherence of long texts such as those used in Experiment 1. Our new experimental procedure offers a way to access the relationship between temporal changes in the mechanism by which a reader processes text and the structure of the text itself. We expect that further studies along these lines would characterize global coherence.

In past studies, there are various theoretical model of reading processes such as *Structure building framework*, *Construction-integration model*, *Event indexing model* and so on. Some discussion have been done to integrate these models and provide the more comprehensive model of reading comprehension[10]. Mcnamara(2009)[10] concluded that each models explain different spectrum of comprehension processes. Our results of two distinct modes of reading can consist with his suggestion. It can be possible that several reading models of previous studies explain reading comprehension in one mode, and the other models explain that in another mode. If so, it should be reasonable to discuss our broad changes of mode with long text and previous models which focus on the rapid processes at the short text together for more understanding of reading processes.

5 Acknowledgements

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Development of a Motion Learning Support System arranging and showing Several Types of Model Motion

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Traditional motion learning support systems have one coach's motion data as a model motion, although the data is not always the best one. Therefore, we proposed a system showing various types of model motion. On the system, you can select a model motion type from the followings; a coach's motion which you like, the coach's motion whose physique is the most similar to yours, the average motion of all coaches, and the motion which is the nearest to the average. Through an evaluation experiment, we concluded that the system was more helpful than the traditional one.

The Study of Quantitative Evaluation Method of Beauty, Using Basic Figures and Motif Compositions as the Aesthetic Measure

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There exist pictures that people have recognized as great, beyond the borders of cultural differences over the last 100 years. This suggests that such paintings would have certain aesthetic elements in common, and if people are able to recognize them through a shared sense of beauty, it would be possible to study what kinds of properties influence people's evaluation of paintings.

Based on the tentative theory that "beauty should be easy-to-understand, super-rational, implicit knowledge". First, focusing on Katsushika Hokusai's paintings, we study the quantitative evaluation method of the level of impressions of beauty, with the hypothesis that "the number of the patterns of beauty in the picture at the initial viewing should be equal to the aesthetic level of beauty". In this study, we defined that "beauty" is caused by positive awareness and pleasantness.

We considered that beauty (pleasantness and positive awareness) would be indicated by physical (line, figure) and psychological (symmetry, complexity, order) factors caused by patterns of beauty existing in the picture.

Currently we are trying to automatically calculate the level of beauty by using image processing, based on the ideas that (1) the similarity ratio of the motif's shape and basic figures, (2) the matching ratio of composition rules and motif allocations, both of which can be the patterns of beauty. We adapted some polygons as basic figures which have high aesthetic ratio defined by Birkooff, such as a square, triangle and circle. In our previous experiment the participants were asked to subjectively apply these basic figures to the motif of paintings. Based on that result, we calculated (1) the similarity ratio of applied figure and original basic shapes, and (2) the matching rate of composition rules and motif allocations using center gravity of fitted figures and Hokusai's composition rules.

Presently, in 2 cases, the levels of beauty of original pictures are higher than the altered pictures. There are some issues I would like to raise, how to add appropriate weights for each motif, how people can fit the basic figures to the picture's motifs with proper sizes and positions. To implement these processes into the program, we are now trying to construct the algorithms for a quantitative evaluation method of beauty.

Control strategy of biped walking of humans that acquired through evolution: from the view point of variance control

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Bernstein, a Russian physiologist in the 20th century, discovered that the arm trajectory of a skilled blacksmith showed variance in every trial during a hitting task, however, his hammer hit the target precisely. From this observation Bernstein concluded that our nervous system exploits joint coordination (joint synergy) mutual compensation of the variance of the joint angles, at some critical points to accomplish a task. During walking, the leg joint trajectories also show some variability in every stride. In our previous study, we analyzed the leg joint synergy from the variance of the leg joint trajectory during bipedal walking of humans and Japanese macaques (M. fuscata) by the UCM (UnControlled Manifold) analysis in order to investigate the critical points to realize stable bipedal walking. The results show that in human walking the variance of the toe position relative to the hip position is suppressed by the joint synergy around the second double support phase and the toe position around the moment when the toe passes the lowest position during leg swing. The former is the important period to stabilize the trunk posture and the latter is important to avoid stumbling. Contrary the amplitude of joint synergy of the bipedal walking of macaques was much lower than that of humans during the second double support phase. These results suggest that the utilization of joint synergy during the second double support phase is a control strategy that humans acquired through evolution. Although the effect of the variance of each joint angle on the toe position depends on the amplitude of joint synergy, the leg posture itself also affects the amount of the variance of the toe position. In this study, we have investigated the difference of the leg postures during walking between humans and macaques from the view point of the suppression of the variance of the toe position relative to the hip position. We will report how the leg posture and joint synergy are organized in order to realize stable walking and how the organization manner is different between humans and macaques.

INVESTIGATING THE RELATIONSHIP BETWEEN GROOVE FEELING AND ACOUSTICAL CHARACTERISTICS REGARDING ISOCHRONALLY-PLAYED PERCUSSIVE SOUNDS

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Background
While eliciting groove feeling is regarded as a crucial skill in popular music especially for drummers, the relationship between groove feeling and acoustical characteristics is still unknown.

Aims
The aim of this study was to investigate the acoustical characteristics affecting the rating of groove feeling by conducting a subjective evaluation experiment.

Method
Six percussionists and drummers participated in the recording of stimuli. A ride cymbal was used for the recording, and the performers played 64 quarter notes at five various tempos including 60, 120, 180, 240, and 300 bpm. The tempo was presented for 20 seconds by a metronome before playing, whereas no metronomic guidance was provided during the recording. After the recording session, the middle 32 attacks were extracted, and the mean of inter-onset interval or IOI (s), the standard deviation of IOI (s), the mean of IOI ratios between consecutive notes (%), the standard deviation of IOI ratios between consecutive notes (%), the mean of sound power ratios between consecutive notes (%), the standard deviation of sound power ratios between consecutive notes (%), and the spectral centroid (Hz) of each stimulus were extracted as acoustical characteristics.
Then, a subjective evaluation experiment was conducted, in which 15 participants rated the groove feeling of each stimulus. In the experiment, participants listened to the stimuli with headphones in random order and rated each stimulus on the computer using seven point rating scale. The term "groove feeling" was defined as "a feeling that elicit body movement while listening."

Results
A stepwise multiple regression analysis was conducted to investigate the acoustical characteristics affecting the groove rating. In the analysis, the mean rating of each stimulus was set as dependent variable, and the extracted seven acoustical characteristics were set as independent variables. As a result, the standard deviation of IOI, and the standard deviation of sound power ratios between consecutive notes were significantly affecting the groove rating ($p < .05$). Furthermore, the following model was proposed in which y represents the groove rating (one to seven points), x_1 represents the standard deviation of IOI (s), and x_2 represents the standard deviation of sound power ratios between consecutive notes (%).

$$y = 0.23 - 43.14x_1 + 0.035x_2$$

Discussion
The result showed that the standard deviation of IOI was significantly affecting the groove rating. In addition, the standardized partial regression coefficient suggested that less variation in tempo elicits higher groove feeling. The standard deviation of sound power ratios between consecutive notes was also significantly affecting the rating. Furthermore, the standardized partial regression coefficient suggested that high groove feeling could be obtained by having greater variation in accents.

Conclusion
In this study, the relationship between acoustical characteristics and groove feeling was investigated. The result showed that the variation of tempo and the variation of accents were significantly affecting the groove rating ($p < .05$). This suggests that (1) less variation in tempo elicits higher groove feeling, and (2) greater variation in accents produces higher groove feeling.

Analysis of acceleration data of the poles in Nordic walking

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Tokyo Polytechnic University

Nordic walking, that is a walking with poles, is known as an effective aerobic activity that uses the whole body, including the muscles of not only the lower body but also the arms and the upper body. The benefits of Nordic walking are that anyone can begin easily regardless of the season, and the effect of the exercise is realized in a short time. Created in Finland, the popularity of Nordic walking is rising around Europe. Recently, Nordic walking has received increased attention from middle-aged people, even in Japan. Previous studies aimed at scientific verification of Nordic walking mainly focused on the alleviation of the load on the legs provided by the poles, and on the energy consumption. Although it is expected that the difference of the load on the legs and the energy consumption occurs with technical mastery of the poles, detailed research has not yet been conducted. The technique of using the poles is explained from a visual viewpoint at an instruction site. However, there is no research that has analyzed the pole work from the perspective of physical movements. Therefore, in our study we analyzed the techniques of both experts and beginners of Nordic walking in order to gather basic data about the differences between them. In this research, we developed a system to acquire data using 3-axis accelerometers attached to the tip and grip of the poles used in Nordic walking. The sensors do not disturb body movements because they have their own batteries and send data to a PC via wireless using ZigBee. We collected and analyzed the data from both experts and beginners using the system. The results of frequency analysis of the acceleration indicated that there were two or more large peaks in the data of the experts, while there was only one large peak in the data of the beginners. We suggest the peak around about 1 Hz in the both data sets indicates the pace of the walk. There is the peak in the beginners' data, while the experts' data has it and also a higher peak. The difference will be a useful index to differentiate between experts and beginners. We expect that it is possible to develop systems to improve pole work in Nordic walking by recognizing the index via signals such as vibration or sound.

Improvement of QoL by integration and analysis of nursing care life log and academic medical and health information infrastructure

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The quality depth and breath of nursing care records varies depending on each care worker's years of experience. It is difficult to share a complete picture of care receivers' information among other care workers just by recording the mere facts. Care workers who see care receivers on a daily basis require detailed nursing care records to supplement and confirm their own observations. With these records, they can improve the care they provide and can better educate other people engaged in care work. To further improve care work operations, it is necessary to solve the issues stated earlier and to develop detailed care record systems using electronic devices. In this study, key vocabulary from care records was used to compare different care receivers and provide care workers with additional information and insights on their care receivers. This study also examines the contents of care records, which enables to share the condition of care receivers among care workers. As a result, it is conceivable that this analysis will help provide care workers with the best information to care for care receivers. This study shows possibilities both in analyzing care records and in designing care record systems using electronic devices. In this study, we analyzed nursing care life log, visualized nursing care action, and realized a method to validate. Feedback from the results are given to the nursing care field, then they share the nursing care records among caregivers to allow them to improve good use of QoL.

For the academic medical and health information infrastructure, it is necessary to collect clinical data of the entire building and the medical area of the system for collecting long-term data on a large scale. Furthermore, an efficient medical care should be sought. To verify the improvement and cost effectiveness of medical care, continuous data collection is important. In the University of Miyazaki Hospital, the need for a data warehouse is desired. In the medical environment in University of Miyazaki Hospital, information technology by the electronic medical record is progressing, utilization of realistic time electronic medical record data is being requested. We collect and accumulate data from diverse and large amount of medical record data generated from the hospital business. Then, it is necessary to go to promote DWH to secondary use the electronic medical record data.

Whole-body coordination skill for dynamic balancing on a slackline

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The purpose of the present study is to reveal the skills for slacklining. A slackline is a flat belt tightly spanned between two anchor points. Because it bounces and swings in all directions, keeping balanced on it is difficult. Since slacklining started as a balance sport in 2007 in Europe, it has spread over the world, and international contests have been held wherein competitors demonstrate various acrobatic skills such as jumping on a line.

Although slacklining has progressively spread as both a balance sport and balance training, research on it is relatively sparse. Most existing studies have focused on the effects of slackline training on balance ability, and very few studies have focused on slacklining skills (a case study). In the practical field of slackline training, instructors share their skills based on personal experience. In a basic slackline course, they begin by teaching a fundamental skill, such as single-leg standing on a slackline, by explaining how they do it. However, such first-person perspectives on slacklining skills have not been scientifically investigated.

According to the instructors' knowledge based on personal experience, we hypothesize the following skills for single-leg standing on the slackline: To maintain whole-body balance in a horizontal direction, one should raise both hands high and coordinate them in parallel; in the vertical direction, one should flexibly bend to reduce the line's fluctuations; in the anteroposterior direction, one should maintain a straight back to keep the center of gravity vertically balanced over the heel of the standing leg and the line.

As a first step toward understanding the slacklining skill, the present study will examine these hypotheses to reveal the skill of single-leg standing on the slackline by comparing the performances of novice and expert groups. A three-dimensional motion capture system will capture whole-body motion, and kinematic data will be analyzed in terms of the hypotheses presented above (parallel bimanual coordination, flexible knee coordination, and stable positioning of center of gravity).

The pilot study comparing performances between novice and experienced players is in progress. In the current workshop, our hypotheses, experimental design, and pilot data will be presented and discussed. We plan to not only describe the skill based on kinematic data analysis from a third-person perspective, but also describe it by interviewing top-level players from a first-person perspective. In future, we aim to suggest safer and more effective training methods based on the knowledge obtained by the present study.

Effects of slackline training on dynamic postural balancing

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The purpose of the present study is to reveal the effects of slackline training on dynamic postural balancing. A slackline is a flat belt made from nylon or polyester, tightly spanned between two anchor points. As it bounces and swings in all directions, keeping balanced on it is difficult. Slacklining, thus, requires one to dynamically and flexibly modulate whole-body coordination. Since slacklining is expected to improve postural balance, it is widely used in balance training for not only top-level athletes but also for the rehabilitation of the elderly or those with motor disorders.

Stabilizing one ' s own body and orienting to dynamic environment is an essential physical ability for human skill acquisition/development/improvement. The ability to adapt to unpredictable noise or perturbations – dynamic embodied adaptability – is related to high sensitivity to changes in the environment and in one's own body, as well as to rapid, flexible organization of the embodied system (i.e., synergy). This ability also involves human embodied skills and is an important research topic in Skill Science.

However no previous studies have investigated the effect of slackline training in terms of dynamic embodied adaptability. A few studies have evaluated postural stability in terms of static measurements based on trajectory length or velocity of the center of pressure (COP). However, because such static measurements of postural stability define less movement of the COP as indicating more stability, they are inappropriate for evaluating human postural fluctuation and dynamic embodied adaptability, which is non-linear and non-stationary.

The present study aims to reveal the types of balance ability improved by the slackline training, as well as how such training causes improvement. To do so, we will consider not only static measurements but also dynamic measurements, calculated by nonlinear time series analyses. In the present experiment, healthy young participants will be randomly assigned to two groups: training and control group. The former will be required to participate in the 20 minutes slackline training, while the latter group will be asked to relax and hold still for 20 minutes. The balancing abilities of each participant will be evaluated before and after the 20 minutes session. Results of static and dynamic measurements of two groups will be compared.

The preliminary experiment is in progress. A few sample data have been obtained, and their COP time series are being analyzed. In the current workshop,

we will present the experimental method, and some of analyzed data will be reported.

Analysis of Hula Hoop Skills by using Dynamic Time Warping and Meta Cognition

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This study aims at discovering useful insight on an acquisition process of hula hoop skills. We employ two approaches to achieve this objective. The first approach is the motion analysis. We analyze time series datasets of body motions by effectively utilizing dynamic time warping(DTW)[1] and try to detect some critical points or changing points in the acquisition processes. The second approach is the meta-cognition. We employ a hexagonal memo pad named 'hex'[2] which provides cycles of "write, layout, and think" for users to recognize interactions between one's own body and the surrounding environment. By considering the results from two approaches of motion analysis and meta-cognition simultaneously, we can expect to effectively analyze the process of skill acquisition.

As a target skill for the analysis in this study, we select the most fundamental motion of hula hoop, *i.e.* hooping around the waist. In addition, as one of the advanced skills, we also discuss the developmental process of chest hooping, *i.e.* hooping around the chest.

By a careful consideration of the hex on the basic skill, we derive a hypothesis that the acquisition process of the basic skill consists of the following five stages. First, subjects rotate hula hoop only several times by using acceleration. Second, they take notice of the rhythm of rotation. Third, they perceive a sense of going down of the hoop. Fourth, they obtain a technique to return the hoop to the original position. Finally, they acquire an energy-saving method for the hooping. The results of the motion analysis also support this hypothesis partially. By applying DTW to the motion of torso, three periods with two changing points are found in the acquisition process of basic skill of a certain subject. We confirm the correspondence between the five stages from meta-cognition and three periods from motion analysis.

As similar to the basic skill, six stages are indicated in the acquisition process of chest hooping. Compared to the process of the basic skill, there are two notable characteristics. The subjects find out unrelated body parts in an early stage and they focus on the motion of the hoop. The results of motion analysis show a time lag between a changing point and skill acquisition point. This time lag can be explained naturally by the six stage process.

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Ecology of skills: How do we control the encounters with the environment?

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A mathematical biologist Robert Rosen once pointed out succinctly that a function of an organism can never be understood in terms of its internal structure simply because "a function requires an external context; a structure does not (Rosen, 2000, p.25)." Our skills are a form of function which is inherently directed toward controlling the encounters with the environment that afford benefit or injury. In this talk, I discuss how the emphasis on *encounters* between animal and the environment may be useful in guiding the research on skills. The talk consists of three parts: (1) what our skilled behavior is directed to, (2) dynamics of exploratory movement, and (3) informational basis for prospective control of encounters. The first part considers the issue of what structures the skilled behavior of an animal *as a whole*. It presents an empirical example of assembly of multi-element systems toward controlling the functionally-specific relationships to the environment. The second part focuses on a special kind of encounters in which an animal hunts for perceptual information. I highlight the recent finding about the characteristic dynamics of exploratory movement that effectively resonates to the ambient information. The final part of the talk discusses the issue of how the values of our *future* encounters with the environment can causally affect the course of our *current* behavior. Each part of the talk includes empirical studies on craftsmen (Nonaka & Bril, 2014), an artist (Nonaka, 2013), child development (Nonaka & Sasaki, 2009), and evolution of human tool-use (Nonaka, Bril, & Rein, 2010; Nonaka, 2012).

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