A Cognitive Model of Acquiring Embodied Expertise Through Meta-cognitive Verbalization

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Summary

Based on the conjecture that acquisition of embodied expertise is a phenomenon that occurs through interactions among the learner's verbal thoughts, perception, physical movements and the surrounding environment, Suwa [2005b] has claimed the significance of dealing with subjective data such as verbalized thoughts in researches on embodied skills, and has advocated a theory on meta-cognitive verbalization. The present paper, based on the empirical findings in playing darts game, provides a cognitive model of embodied meta-cognitive verbalization. This model theorizes what kinds of cognitive processes involve embodied meta-cognitive verbalization, and how these processes change a learner's thoughts, perception, actions and self-awareness to those, and thereby promote acquisition of embodied expertise.

1. Introduction

Exploration of human intelligence, in psychology, philosophy, and recently in cognitive science and artificial intelligence, has accumulated long history over centuries. We do not yet, however, know much about our intelligence. Nobody doubts that what Polanyi [Polanyi 66] called tacit knowledge may constitute the central components of intelligence.

Embodied expertise, such as skills in playing sports or in playing musical instruments, seems to be typical tacit knowledge. It is believed that our body knows more than we can verbalize. It might be impossible to verbalize all our own body knows and can do. This statement, however, does not necessarily mean that we can never verbalize what our body knows. We may be able to verbalize some of it.

In recent years we have advocated a theory that meta-cognitively verbalizing what one's body does and feels could serve as a tool for development of embodied expertise [Suwa 05b], and accumulated case studies in domains like sports and music (e.g. [Suwa 04; 05a]). The theory on verbalization of embodied expertise, although seemingly paradoxical if believing in Polanyi's statement, is worth further exploration, because supportive evidence and theories are ubiquitous. One anecdotal evidence suggesting the plausibility of that theory is a statement by Ichiro, one of the most successful Major League baseball players; he has repeatedly talked of something that means that efforts to conceptually theorize how he perceives the ball and how his body reacts and hits it have been important as he became one of "the best of the pros"[1]. The *situated cognition* theory advocated around '80, too, has a supportive notion that conceptual thoughts, perception and bodily performance affect one another and thereby develop in a coordinated manner (e.g. [Clancey 97]). What logically follows it is that verbalization may affect perception and bodily performance. Another theory on externalization of thoughts actively discussed in cognitive science in 80's and 90's is supportive, too, saying that externalizing one's own thoughts, such as by jotting down drawings (e.g. [Larkin 87]) on paper or writing memos, encourages discoveries of unheeded aspects beyond what we have already conceptualized. Verbalization of thoughts is a kind of externalization. It seems natural that meta-cognitive verbalization may encourage discoveries of unheeded variables of one's own body.

The purpose of this paper is to propose a cognitive model of acquiring embodied expertise through

[1] Ichiro talked on this in interviews in some TV programs of by NHK BS1, such as "Gunzou of Japanese Major Leaguer – Ichiro's genuine value in the second year" broadcast in January in 2003, and "Gunzou of Japanese Major Leaguer – Ichiro's trajectory throughout the fourth year" broadcast in January in 2005.

meta-cognitive verbalization, based on empirical findings and implications from case studies in sports.

2. A Theory on Embodied Meta-cognitive Verbalization

2.1 What is Embodied Meta-cognition in Our Sense

As discussed in the introduction, the connotation of situated cognition theory is co-evolution of thoughts, perception and actions. Besides perception from the environment changing one's thoughts, having new thoughts will bring about new ways of perception. Moving bodies and acting onto the environment will promote new thoughts and perception, too. Cognition is not just confined to thoughts in mind, but the entire interactions among thoughts, perception and body movements and actions.

Meta-cognition is, by its definition, cognition of cognition; i.e. an act of reflecting on one's own thoughts, perception and movements. What we mean by "reflecting on" consists of two components; (1) self-awareness of what we think, what we perceive, and how we move our body, and (2) thereby verbalization of them. Perception consists of two kinds; one is to have senses from the environment, and the other is having a sense of own body through the proprioceptive system [Bernstein 96]. Therefore, what should be verbalized in meta-cognition is

- what one thinks or thought
- how one moves or moved body parts
- what one perceives from the environment through five senses, and
- the sense of our body though the proprioceptive system (as a result of moving muscles and joints).

Since perception and body movements are usually performed without self-awareness, it is almost impossible to verbalize the four kinds of cognition perfectly. Important is, however, that one makes mental efforts to verbalize as much as one can be self-aware of and externalize as vocal tokens.

Why does meta-cognitive verbalization serve as a tool for development of embodied expertise? According to the notion of affordance in ecological psychology (e.g. [Gibson 55]), detecting variables in one's body and the surrounding environment and thereby discovering new relations between one's body and the environment is the essence of learning as a living creature in the environment. Nakashima et. al [Nakashima 06] theorized that meta-cognitive verbalization is a kind of *observation from the endo-system view*; an act of a constituent of a system observing, from the internal viewpoint, what is occurring within the system. That is, a person and the surrounding environment constitute a system, where his thoughts, perception, and actions are the interactions occurring within the system. When he does meta-cognitive verbalization, he as a constituent of the system reflects on and verbalizes the very interactions occurring within the system. Observation from the endo-system view, due to the nature of the act, will affect the very interactions, which means in this case that the person will obtain new ways of seeing the environment, acting on it and thinking. This way, embodied meta-cognitive verbalization may promote discovery of new relations between one's body and the environment and thereby acquisition of embodied expertise.

The purpose of verbalization is not a correct monitoring and thereby a control of the movement of one's own body parts, but rather augmentation of self-awareness of the interactions that occurs between one's body and the surrounding environment. Augmented self-awareness will promote discovery of new relations between body and environment. That is why we call meta-cognitive verbalization a tool, not the purpose [Suwa 05b]. What follows this basic notion is the following useful heuristics in practical situations.

> "One should not stick too much to aiming at correctness or consistency of all the ideas and thoughts. Rather one may want to understand that verbalization is just an externalization of what one has temporarily modeled, and that it will facilitate discoveries of new variables and models, which may or may not end up with denial or contradiction of what one has verbalized at the moment."

We conjecture that if one sticks to correctness or consistency too much, one is easily fixated to what one has verbalized earlier and thus becomes unable to maintain open and keen eyes to so-far-implicit or unheeded variables in the environment as well as to new relations between the body and the environment. Verbalization can be a tool for development, but could be a strong cause for fixation as well.

2.2 Comparison to Conventional Meta-cognition

Researches on meta-cognition are not new. Reflection, introspection, retrospection, and meta-cognition are sibling cognitive acts of reflection on oneself. Psychological studies have provided evidence for their effectiveness in learning (e.g. [Hacker 98]), although each having its own pros and cons. For simplicity, we refer to those as the conventional meta-cognition.

The first significant difference between embodied meta-cognition in our sense and the conventional ones is the following. The target of verbalization in our sense is not just thoughts but also perception, proprioceptive senses, and body movements. On the other hand, in most conventional studies, it was mostly thoughts. That is, meta-cognition in the conventional sense was an act of externalizing thoughts on thoughts, especially self-awareness of problem-solving processes (e.g. [Hacker 98]). Issues on self-awareness and verbalization of perception and body movements have rarely been addressed. Exploration of embodied expertise, however, requires putting on the podium of rigorous research the issues of self-awareness and verbalization of not only thoughts but also perception and bodily movements. Otherwise, embodied aspects of skills would be neglected, which could be fatal for exploration of embodied skills. In other words, we conjecture, the conventional studies did not need to deal with self-awareness of perception and body movements because their target was mental or conceptual skills.

The second notable difference is that embodied meta-cognition in our sense is an act of observation from the endo-system view (as discussed earlier) whereas the conventional meta-cognition was meant to be an act of objective observation of one's own thoughts from the outside view [Nakashima 06]. Varela [Varela 03] argues that in order to know more about human intelligence we would need to approach to "spontaneous and reflective dimensions of human experience" (p.xviii), which cannot be satisfactorily explored by analysis from the outside viewpoint. Further, Varela discussed that what we call conventional meta-cognition is "an abstract and disembodied activity" (p.27), and that "an embodied (mindful), open-ended reflection" (p.27) is necessary to study "human experience". An abstract and disembodied activity such as thoughts on thoughts cannot explore embodied relations between one's body and the surrounding environment. We claim that meta-cognitive verbalization serves as an embodied reflection because it is a reflective act of externalizing proprioceptive senses as well as five senses from the environment from the endo-system viewpoint.

The third difference lies in their purposes. The purpose of conventional meta-cognition is to monitor one's own actions and thoughts objectively and correctly, and thereby to control oneself by self-awareness. Whereas, the purpose of embodied meta-cognitive verbalization is to serve as a driving-force for augmenting what one can feel and think. In other words, the act of verbalization itself is part of "human experience", not an objective method for monitoring "human experience". Varela provided similar statements, characterizing an embodied open-ended reflection as "mindful/awareness as a method of observation in situ" (p.32) and arguing that "reflection is not just on experience, but reflection is a form of experience itself" (p.27).

3. Empirical Findings about Meta-cognition in Playing Darts

A participant to the experiment was a 22-year old male university student. He practiced playing darts, aiming at improvement of throwing skills. For 7 months, from the end of February 2006 through the end of September, he played 413 darts games on 56 days, competing with a friend of his. He did 7 to 8 games a day on average. The target darts game in this research is the one in which to compete in the total score of 24 throws (3 throws in one time, 8 times). Every time he finished one game (24 throws), he meta-cognitively verbalized, in the form of writing down on a notebook, how he used and moved body parts, what kind of mindset he had, what he perceived in darts board and the surrounding environment and how, and so on.

3.1 Improvement of Score

How did his performance improve during 7 months? Figure 1 shows how 3-day moving average of scores changed during the period, with the horizontal axis being the date he played games and the vertical axis being the average score. The number of games he played in one day varied, ranging 2 games a day to 16. Until the end of July, the score underwent minor ups and downs between 400 and 440. Although there were 4 time local peaks, shown by four red circles,

during the period, the global observation is that there was no improvement of his performance. From the beginning of August, however, the score suddenly rose remarkably (shown in the big red circle on the right side), and the average during the last month reached approximately 480. We will call the period from February through the end of July "before-improvement", and the period after August "during-improvement".

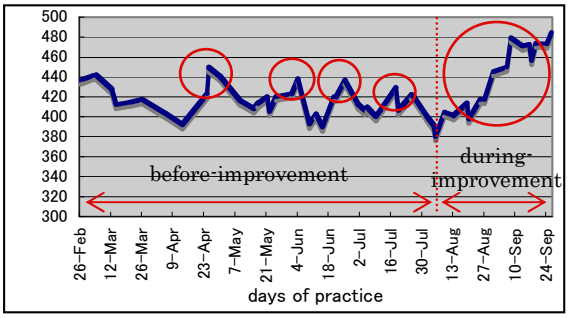

Figure 1 Improvement of scores of the darts player.

3.2 Variables in Body

According to ecological psychology (e.g. [Gibson 55]), people become able to draw attention to variables that was imperceptible earlier as they learn. Variables that are relevant to acquisition of embodied skills exist ubiquitously in one's own body and the surrounding environment. For example, suppose that a right-handed baseball batter warns himself to bend the left elbow without stiff tension during the process from backswing to impact. In this case, "the angle of the left elbow bending" and "its trajectory" are variables in body.

As a simple measure of variables that our participant, the darts player, attended to, we coded words about body parts from the sentences he wrote in the notebook, and investigated how the number of these words changed during the 7 months. Figure 2 shows 3-day moving average of the number of words about body parts in the sentences written for one game (24 throws). Globally speaking, the number of words gradually decreased from February to the middle of July, i.e. as shown by the blue arrow, and then all of a sudden increased remarkably for a month or so until the end of August, i.e. as shown by the pink arrow. A more precise observation of the period of global decrease is that there were local peaks three times, shown as green circles.

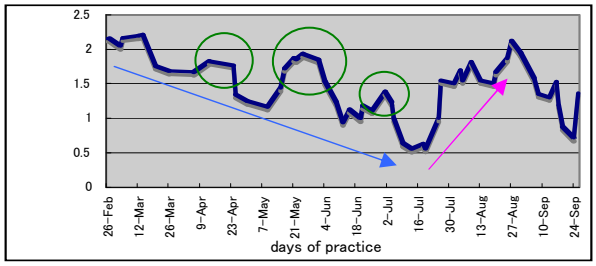

Figure 2 Changes of the number of variables about body parts for the 7 months.

The maximum value of the vertical axis is approximately a little more than 2. This is the number calculated by 3-day moving average with the number of games a day being 7 to 8 on average. This means that he attended to more than a dozen body parts a day at maximum, including variables attended to repeatedly.

The comparison between Figures 1 and 2 provides a significant finding. In the "before-improvement" period, every time and immediately after the number of variables about body parts had a local peak (the green circles in Figure 2), the score had a local peak (the leftmost, the second left and the fourth left blue circles in Figure 1), too. Further, immediately after the sudden increase of the number of variables about body parts for a month beginning at the end of July, the score reached the "during-improvement" period. The phenomenon that the score increased immediately after or at the same time as the increase of attention to body parts matches the theory of learning in ecological psychology. We interpret, therefore, that this is a significant and general finding in acquisition of embodied skills.

3.3 Degree of Detailed-ness of Words about Body Parts

Variables about body parts vary, ranging from words indicating the detailed and small body parts to words for roughly denoting large areas of body or the entire body. In our previous research on bowling [Suwa 06], we obtained a significant finding that the period in which words about detailed body parts increase and the period in which words for rough denotation increase occurred in turns. Further significantly, we found that, immediately after the increase of words about detailed body parts halted and words for rough denotation began to increase in turn, performance of the learner became improved remarkably or more refined.

In order to investigate reproducibility in a different case study, we examined how the degree of detailed-ness of words changed in this research as well. Based on Suwa and Itoh's method [Suwa 06], we prepared five categories of the detailed-ness of words, ranging from a rough word such as "the entire body" being defined as Detailed-ness 1, to "upper body" and "lower body" as Detailed-ness 2, and to words indicating one finger or its tip as Detailed-ness 5. Although, in Suwa and Ito's study, a more detailed category indicating small parts of skin on the tip of a finger was prepared, called Detailed-ness 6, our participant in the present research did not write words with such detail.

Then, by classifying words belonging to Detailed-ness 1 through 3 as "rough" and words belonging to Detailed-ness 4 and 5 as "detailed", we calculated, for each day, the percentage of the number of rough words and that of detailed words. Figure 3 shows 3-day moving average of the percentages through the entire 56-day (7 months) period. The vertical axis is the percentages of rough and detailed words, with the red area indicating detailed words and the blue one rough. Similarly as the case study in bowling, the period in which detailed words increased and the period in which rough words increased occurred in turns in this research as well. It is observed that both periods took turns three times during the whole months. Comparing Figure 3 to the change of score in Figure 1, immediately after or together with the halt of increase of detailed words and a shift to the increase of rough words, the score made a local peak or reached a remarkable jump. A finding similar as Suwa and Itoh's has been obtained in this research as well.

These findings suggest that the turns between the increase of detailed words and that of rough words observable in a learner's verbalization are eloquent signs indicating significant aspects of the cognitive processes in acquisition of embodied skills. We further presume that the changes of the detailed-ness of words could be in themselves a significant driving-force for promoting the improvement of embodied skills.

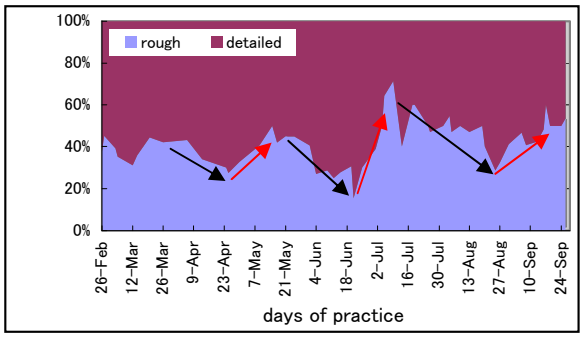

Figure 3 Changes of the percentage of the number of detailed words about body parts and that of rough words for the 7 months.

3.4 Words Denoting Relations among Variables

We conjecture that merely becoming able to attend to more and more number of so-far implicit variables does not suffice to learning. Becoming able to draw attention to relations among variables and thereby theorizing how those variables relate each other and relevant to the execution of the target skills is, we assume, necessary for a learner to acquire embodied skills. Based on this conjecture, we examined the changes of the number of relations among variables the darts player attended to.

We segmented all the sentences he wrote in a way that one segment represents one semantic bunch, consisting of one sentence sometimes, and more than one sentence sometimes. Then, for each segment, we analyzed how many concepts the semantic bunch relates to one another. Here what is meant by concepts are variables about body parts he attended to, proprioceptive senses he had, ways of keeping mindset, ways of perception, variables he perceived in the environment, technical concepts about the darts game, words for representing evaluation of his own performance, and so on.

We found that the number of concepts one segment relates ranges from one to nine throughout the entire 7 months. We call a segment describing only one concept "*1*-concept segment", and a segment relating n-concepts "*n*-concepts segment". For each of the 56 days he played the darts game, we calculated the ratio of the number of "*n*-concept(s) segments" for each *n* to the total segments in the day. Figure 4 shows how 3-day moving average of the ratios for each of the *n*-concepts segments changed during the entire 7 months.

At the beginning months, *1-to-3*-concepts segments were dominant. Gradually, however, *larger-n*-concepts segments began to occupy percentages to a more

degree, as observed in Fig.4 in which most boundary lines between the area of (*n-1*)-concepts segments and that of *n*-concepts ones are in a right-lower pattern. In April, *5-to-7*-concepts segment appeared for the first time, as shown in the leftmost red circle in Fig.4. The ratios of those segments began to occupy percentages to a more degree in June, as shown in the center red circle. At the end of July, *8*-concepts segments and *9*-concepts segments appeared for the first time, and *more-than-5*-cocnepts segments constantly occupy percentages to a certain degree, as shown in the rightmost red circle. Interestingly, the periods indicated by the three red circles exactly coincided with the first local peak of the score, the third local peak, and the "during-improvement" period in Fig.1. Especially the coincidence between the rightmost red circle in Fig.4 and the "during-improvement" period shown in Fig.1 seems not accidental. Rather, it suggests that becoming able to constantly verbalize relations among many concepts may be a cause of sudden remarkable improvement of performance.

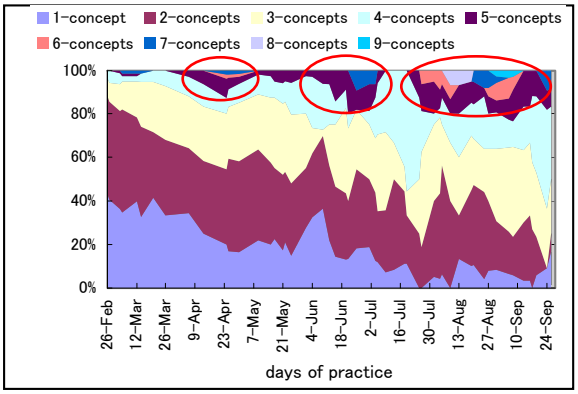

Figure 4 Changes of the percentages of "*n*-concepts segments" for the 7 months.

4. Cognitive Model of Meta-cognitive Verbalization

What kind of cognitive processes does a custom of embodied meta-cognitive verbalization give rise to, and how does it promote development of embodied skills? Here we propose a cognitive model of it, based on the relevant theories on cognition discussed in Sections 1 and 2, and on the insights obtained from the case studies in sports.

4.1 Seven Processes of Meta-cognitive Verbalization

Embodied meta-cognition proposed in this paper is constituted by three components, as shown in Fig. 5; (1) verbalization, (2) perception including having senses from the environment and proprioceptive senses, and (3) body movements. What we mean by perception is "internal image" of the surrounding world, objects in it or proprioceptive senses that the body forms in acting in the world. We distinguish it from "words about perception". The latter should be categorized into verbalization, rather. The seven arrows connecting the three components denote the significant processes in meta-cognitive verbalization. In this subsection, we will explain each process in detail.

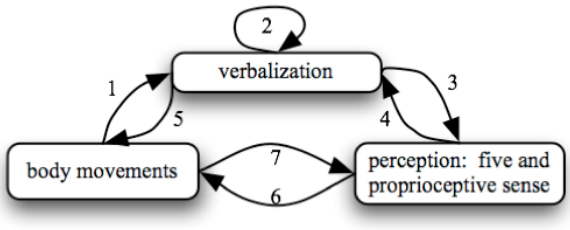

Figure 5 Significant processes in meta-cognitive verbalization.

4.1.1 Arrow 1: Verbalizing body

A custom of meta-cognition starts by verbalizing body movements and perception, i.e. Arrows 1 and 4 in Fig.5. Due to its tacit nature, what can be verbalized may be a little at first, with only a few new variables being detected.

4.1.2 Arrow 2: Verbalization generates verbalization

Verbalization, even a little at first, generates another verbalization, i.e. the self-pointing Arrow 2 in Fig.5. This is because we are living creatures thinking through language and associative linkage among concepts is the major means of thinking. This is also because verbalization is a kind of externalization, which facilitates discoveries of relations among externalized concepts that were so-far unrelated. It is just as externalized media like design sketches encourage detection of implicit relations between elements that were sketched at different times during a design process [Suwa 00]. This is what the cognitive theory on externalization suggests, as discussed in the introduction. Augmentation of verbalization represented by Arrow 2 seems plausible empirically as well; it is often the case in a daily life that as we write sentences we find relevant new concepts that were

beyond what we had intended to write originally.

4.1.3 Arrow 3: Verbalization affects perception

Further, verbalization affects ways in which perception occurs, i.e. Arrow 3 in Fig.5. This is the cognitive effect that the theory of situated cognition predicts as discussed in the introduction. A good example of this is the famous image of Dalmatian [Gregory 70] often used in psychology to discuss the nature of perception. Due to its very rough resolution, many people cannot answer what is pictured in the image. But, if questioned "Where is a dog?", most of them can suddenly see a dog sniffing on the ground. The existence of a word "dog" and thinking of a concept "dog" changes the way in which perception occurs. It is a generally accepted notion in psychology, philosophy and cognitive science that perception is not a passive act of receiving incoming signals from environment, but an active act of exploring and detecting in the environment variables necessary for one's own living. Therefore, augmentation of what one can verbalize will augment variables that one can perceive in one's body and the surrounding environment.

4.1.4 Arrow 4: Change of perception augments verbalization

If perception changes, what can be verbalized and the number of detectable variables increase, i.e. Arrow 4 in Fig.5. Both processes represented by Arrows 3 and 4 constitute a cycle in which verbalization and perception affect each other and co-evolve. This is the phenomenon of coordination of conceptualization and perception suggested by the theory of situated cognition.

4.1.5 Arrows 5 and 6: Changes of verbalization and perception motivate body movements

The increase of verbalized awareness of variables and the change of perception will motivate moving body in a new manner, i.e. Arrows 5 and 6 in Fig.5.

4.1.6 Arrow 7: Body movements generate new perception

A new way of moving body provides new opportunities of having proprioceptive senses. Further, as the theory of situated cognition suggests, moving body and acting onto the environment promote new ways of perception. This is the process represented by Arrow 7 in Fig.5.

We human beings are more or less meta-cognitive creatures. As long as we think using language, we usually go through the processes represented by Arrows 1, 2, 3, 4, 5. But, as far as something tacit such as embodied skills is concerned, we do not dare to put ourselves into a custom of meta-cognitive verbalization. Most of our cognition undergoes the cyclic processes of Arrows 6 and 7, i.e. acting in the environment, feeling its resultant proprioceptive senses, and perceiving from the new relations between own body and the environment. Compared to this limited cycle, verbalization promotes processes with more varieties and generates richer ways of co-evolution of verbalization, perception and body actions.

4.1.7 Back to Arrow 1

If body movements are renewed, what can be verbalized based on that will change, which starts another cycle.

4.2 Embodied meta-cognition promotes formation of an integrated model for execution of embodied skills

We will explicate the findings obtained from the case study of the darts player, using the cognitive model represented by the processes shown in Fig. 5. Sudden local increases of variables that he is able to be self-aware of and verbalize can be interpreted as phenomena that co-evolution of verbalization and perception, co-evolution of verbalization and body movements, and a self-promoting cycle of verbalization are active and therefore the whole cycle of Fig.5 is being accelerated. Especially, variables that are dominant in a learner's self-awareness and verbalization when meta-cognitive verbalization is being actively accelerated in cycles may be, we believe, "detailed" ones. The moments when the percentage of detailed variables had a peak value as seen in Fig.3 are regarded as ones in which meta-cognitive verbalization is active.

Why is it that the shifts from the increase of detailed variables to that of rough ones coincided with the periods of locally good performance and remarkable improvement? Why is it, further, that verbalization of relations among many concepts coincided with periods of locally good performance and remarkable improvement? What occurs in a learner's cognitive processes in these periods? Comparison of Figs.3 and 4 reveals that the increase of detailed variables exactly

coincided with the period in which self-awareness of relations among larger number of concepts began to occupy percentages to a more degree. This was true to all the three occasions. This suggests that the darts player, during these periods, explored how variables in body parts and in the environment relate one another, and he thought of larger and larger number of variables as time went. We interpret that these were periods of exploring and thereby modeling how the whole body consisting of many parts should function in a way that matches well with the environment in order to execute the target embodied skill. We call it a period of "formation of an integrated model of body and environment".

When a learner thinks that he has reached an understanding of an integrated model, he will try to execute the target skill in a new manner that the model specifies. The dominant cognitive processes are, at this time, Arrows 5 and 6 in Fig.5. The learner does not necessarily, however, attend to all the variables that constitute the integrated model and control each body part verbally. This seems plausible empirically because verbal control usually does not catch up with the speed in moving body parts for the execution of the entire skill. We conjecture, rather, that he or she explores a gestalt feel of proprioceptive senses in moving the entire body in a way that follows the integrated model. Focus only on a few representative variables may imply attention to all the variables and relations constituting the integrated model to feel the gestalt. We interpret that this is why there was a moment of the halt of the increase of detailed words and a subsequent shift to the increase of rough words in turn. We interpret, further, that performance has a better turn or improves remarkably just because the learner moves body following the integrated model that are gained through trial-and-error exploration of very detailed variables and theorization of relations between body and environment.

Once an integrated model is obtained, however, it is never the end of the process of acquisition of embodied skills. If improvement to a certain degree is obtained after the formation of an integrated model, new variables that were so far unheeded become perceptible to a learner. That corresponds to the process represented by Arrow 1 in Fig.5. Meta-cognitive verbalization goes into a new cycle here. When he or she finds many new variables that he or she thinks essential to further development of skills, the learner has to destroy the integrated model, and embark on re-construction of a new model reflecting the newly found variables. At this stage performance could become worse, i.e. a kind of slump. This is a slump due to the discovery of significant variables, and due to a preparatory period before the construction of an integrated model. Again the learner begins to think of relations among many variables, new and old, to re-construct a new integrated model and theorization of how body parts function in match with the environment in execution of the skill. Detailed words and relations among larger number of concepts begin to increase in the learner's verbalization. We interpret that the process of acquisition of embodied skills is a repeated, almost never-ending, cycle of construction, destruction and re-construction of integrated models. An integrated model constructed at one time is always tentative, waiting for being upgraded.

5. Discussions

5.1 Three phases of embodied meta-cognition

We have proposed, in section 4.1, a model on what kinds of cognitive processes embodied meta-cognition gives rise to. Based on this model, we derive here a practical methodology for embodied meta-cognition, i.e. a kind of guideline for carrying out embodied meta-cognition in a domain of acquisition of skills. In order to enrich the co-evolution of verbalization, perception and body actions, i.e. the arrows 1 through 5 in Fig.5, a learner should be aware of, distinguish and entertain the following three steps.

1. Verbalizing embodied expertise little by little
2. "Playing with words" by being free from body constraints
3. Re-paying attention to body with awareness of some new words

The first step is to externalization by words of one's own body movements and perception little by little. The second is a process of "playing with words", i.e. reasoning, opportunistic and free association among concepts and words, abducing a theory and so on, by being free from constraints of body movements. The intention of the second step for the learner should be to come to focus on some "promising" words that were unheeded so far. No grounds, theory, or logical thoughts are needed in selecting what is "promising". The learner has only to select those new words even by intuition. Those new words may be obtained by conversation with other people or just by thinking by himself. This

new attention has become possible because the learner has verbalized body and perception in Step 1, and has reasoned and conducted association in the process of "playing with words". The third step is to move the body and search for new proprioceptive senses by having focused attention to those newly word. Compared to the previous time when the learner moved his or her body without attention to those words, what he or she is now able to perceive will be renewed. That will, then, motivate verbalization of body and perception as another cycle, the first step again. We argue that attention to these three steps could serve as a useful guideline for carrying out embodied meta-cognitive verbalization.

5.2 Co-utilization of evaluation by external sources

We discussed in Section 2.1 that the purpose of embodied meta-cognition is not correct monitoring due to the tacit nature of embodied skills. Embodied meta-cognition should be an act of pursuing an integrated model of body usage in an exploratory manner without sticking to correctness of verbalization. That is for preventing fixation in a pursuit of new variables and models. At the same time, however, it could be a weak point because embodied meta-cognition itself does not assure that meta-cognition proceeds in a better direction. This weak point derives from the intrinsic nature that embodied meta-cognition is an act of observing with an endo-system view [Nakashima 06]. Objective scores of body performance or even subjective evaluation given by coaching staffs should be co-utilized to alleviate the weak point. If bad performance continues, a learner will think that something may be wrong with his or her meta-cognition and revise ways of doing meta-cognition. Evaluation by coaches, good or bad, motivates a learner to revise ways of meta-cognition. Co-utilization of those external sources of evaluation with meta-cognition is significant for preventing a learner from proceeding in a bad direction or being stuck in local minimums.

5.3 Meta-structure of meta-cognition

The third issue to be discussed is infinite "meta" structure of meta-cognition. For example, a person's self-awareness of certain body parts moving this way or that is first-order meta-cognition, whereas thinking of that self-awareness is second-order. This way, meta-cognition done by human beings will possibly have multi-order "meta" structure. In this paper, we refer to the whole cognition having multi-order meta-structure as "meta-cognition". We conjecture that human meta-cognition has no danger of infinite regression of "meta" structure due to the limitation of cognitive capacity. In other words, assuming that human inherent nature naturally puts a limitation on the regression of "meta" structure, we have not provided any heuristics, theory, or methodology for limiting regression to a finite order in the proposed cognitive model of meta-cognition. There is a possibility, however, that stopping the regression at a proper order may make meta-cognition function better. Researches on that is one of significant future work.

This paper provides an idea that verbalization serves as a tool for acquisition of embodied skills and for research on that. Therefore, skills of such living creatures that use language are the target of our research. Further, in order for contents verbalized by the language to be studied properly, the semantic organization of the language needs to be known to us researchers. For these reasons, the proposed theory in this paper targets at human acquisition of embodied skills only, not animal's.

6. Conclusion

Our research is a challenge of augmenting understanding of embodied expertise, i.e. a kind of tacit knowledge, and establishing a methodology for promoting its development. We have advocated a theory that embodied meta-cognitive verbalization serves as a useful and practical tool for it. Verbalization does not assure in a straightforward manner a conversion of tacit knowledge to explicit knowledge sharable and transferable among people. By exploring relations among variables in the body and the environment, the learner becomes able to open keen eyes to so-far implicit or unheeded variables. This means, we conjecture, that he or she goes into deeper tacit areas. Especially, when we deal with embodied skills, tacit areas always remain because the learner explores one's own body deeply, because the surrounding environment is constantly changing, and because what could be regarded as the surrounding environment is open and almost unbounded. Meta-cognitive verbalization is, facing the tacitness of embodied skills, a practical tool for promoting awareness of more subtle perceptual variables in proprioceptive senses and five senses from the

environment, and thereby for improving skills through repeated construction of integrated models of body-environment coordination.

Dealing with subjective data such as meta-cognitive verbalization in researches on embodied skills is indispensable. The reason is the following. We human beings are living creatures using language as a tool for thinking, acting and perceiving. Acquisition of embodied skills is a cognitive phenomenon that occurs through interactions among verbal thoughts, perception, physical movements and the environment. Without the data on the learner's verbal thoughts, the research endeavor does not grasp the whole picture of those interactions.

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