Shuichi Fukuda *Editor*

# Emotional Engineering, Vol. 6

## Understanding Motivation

Springer

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# Preface

The progress of engineering is remarkable. Their primary efforts today, however, are paid to develop better methods or tools for realizing high-quality products. But if we look back, engineering started because we were motivated to create something that could not be obtained from nature and to make our dreams come true.

As Herbert Simon pointed out, rationality is bounded. With increasing number of variables, the problem becomes extremely difficult to solve due to growing computational complexity. Therefore, we cannot optimize in an open world as we did in a closed world. So, Simon proposed Satisficing (Satisfy+Suffice). Satisficing is nothing other than emotional satisfaction. Thus, the rapidly growing complexity of systems calls for emotional engineering approach.

Another important point is that engineering today is final product-based. However, it should be emphasized that not only products, but processes also create values. Abraham Maslow placed self-actualization on the top of the hierarchy of human needs. Humans would like to demonstrate how capable they are. Let us take mountain climbing, for example. If we would like to get to the top of the mountain, then we can ask a helicopter to take us there. But mountain climbers find a difficult route to the top and they challenge. In fact, challenge is the core and mainspring of all human activities.

But current engineering forgot such desires of ours. Even if mountain climbers cannot make it to the top, they would be satisfied if they can move ahead and get closer to the top. Indeed, they could not achieve their goal, but they succeeded in demonstrating their capabilities by moving ahead, although it might be a small step. This gives them a feeling of fulfillment and achievement. They can challenge next time, and they can keep on dreaming. In fact, when they succeed, they will find a more difficult route next time. They would like to keep on challenging. This satisfies another need of humans to grow, which is pointed out by Edward Deci and Richard Ryan. Thus, getting to the top (product, result) is not what they really want. They would like to enjoy the processes of getting there. Consideration of such process values is lacking in today's engineering. Engineers today are looking for a vehicle to take us to the goal with less efforts. But we must remember efforts yield values. The more efforts are needed, the more value is created.

Motivation and emotion share their etymology. They came from the same Latin word movere (= move). Thus, motivation and emotion constitute the following cycle: Cognition (Perception) => Motivation => Decision Making => Action => Emotion. This cycle is repeated in our daily life.

Current engineering focuses their primary attention to the latter part. It proposes new ideas or tools to make our action more efficient. It is goal-oriented or product-focused. But if we remember self-actualization is the highest need of humans, we must pay more attention to the earlier stages, i.e., How do we perceive and how we are getting motivated. In fact, the most important goal of engineering tomorrow will be how we can develop satisfaction. We have been discussing productivity until today, but tomorrow what we should discuss is the degree of satisfaction. What engineers tomorrow must develop is satisfaction. Product-based engineering is quickly fading away.

Additive Manufacturing and 3D Printing (AM3D) are getting wide attention these days. But most of the discussion about them remains still in the traditional framework of product development. Regrettably, how they can produce process values is rarely discussed. But as Maker demonstrates, people would like to actualize themselves. AM3D brings to us the opportunities of feeling fulfillment and achievement.

To accelerate our move toward satisfaction engineering, first we must make clear and understand motivation. In fact, the same environment and situation are perceived differently from person to person. Current engineering discusses environments and situations objectively. But what motivates us are subjective environments and situations. The same environment and situation motivates us in a very different manner from person to person. Therefore, understanding motivation is a crucial step toward satisfaction engineering.

This book contains researches from many different perspectives. To understand motivation, we need to have a broader and more multi-dimensional perspective. It is strongly hoped that this book contributes to understanding the importance of motivation and helps us move ahead toward satisfaction engineering, i.e., engineering tomorrow.

Finally, I would like to thank all authors from the very bottom of my heart for their excellent contributions, and I would also like to thank Mr. Anthony Doyle, Ms. Janet Sterritt, Ms. Viradasarani Natarajan, and Ms. SujithaShree Duraisamy at Springer.

Minato, Japan Shuichi Fukuda

# Contents

# Chapter 1
# Value Rationality

**Shuichi Fukuda**

**Abstract** This chapter points out that to cope with the rapidly expanding open world where there are no boundaries and where changes are frequent and extensive and requirements are too much diversified, we need to step out of the traditional engineering framework of Max Weber's Zweckrationalitaet or instrumental rationality or in another word, the world of explicit knowledge and move toward the world of Wertrationalitaet or value rationality. Values are evaluated based on performance in traditional engineering. But this performance has been none other than functions. So, value in the traditional engineering is very objective. And it is discussed in the framework of theoretical rationality. But to change our minds from instrumental or means-ends rationality to value rationality, we should look at value on a personal basis, i.e., value tomorrow will be very much subjective and personal. And products and services will be developed to generate such personal values. The basic framework of our engineering tomorrow will be value-oriented rationality.

## 1.1 Introduction

Max Weber [1] proposed two types of rationalities: Zweckrationalitaet and Wertrationalitaet (Fig. 1.1).

Zweckrationalitaet is purposive or instrumental rationality. In most discussion about rationality today is about Zweckrationalitaet. We have been pursuing Zweckrationalitaet or instrumental rationality in our engineering. We would like to have theoretical background to realize our goal. In other words, ends were rationally pursued and calculated. To put it in another word, the basic framework of our engineering today is explicit knowledge.

Wertrationalitaet is value-oriented rationality. Weber associated it with motivation and emotion. So, it may be called Emotional Rationality. Herbert Simon

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Max Weber's two types of rationalities

Zweckrationalitaet --- Instrumental Rationality

Wertrationalitaet ----- Value Rationality

**Fig. 1.1** Max Weber's two types of rationalities

pointed out that rationality is bounded [2], so that we cannot carry out optimization if the problem space is very large and has many variables due to computational complexity. Therefore, he proposed Satisficing (Satisfy + Suffice) beyond the bounds of rationality [3]. This is nothing other than emotional satisfaction.

Value was defined by Miles [4] as follows:

$$\text{Value} = \text{Performance/Cost} \tag{1.1}$$

And for many years, functions have been considered as performance. If the functions of a product were good, then its performance was considered good. Although recently service is added, still value is considered in this traditional framework.

Today, we have succeeded in expanding controllability beyond the rational world. However, it is due to our wisdom to apply theoretical rational approach beyond the bounds of the rational world. Thus, we have established the controllable world which is far broader than the rational world (Fig. 1.2). Still, it is within the framework of instrumental rationality. We have been expanding explicit knowledge in our engineering.

It is difficult to find Wertrational or value-oriented rational engineering examples today. But we have to remember that value is very much personal. Value defined by Eq. (1.1) is objective, and it was very much useful in the days when changes were small and products were produced in mass. But true value is subjective, and it is very much associated with emotion.

In this chapter, we will discuss why Wertrational or value-oriented engineering becomes important in this era of frequent and extensive changes and this age of

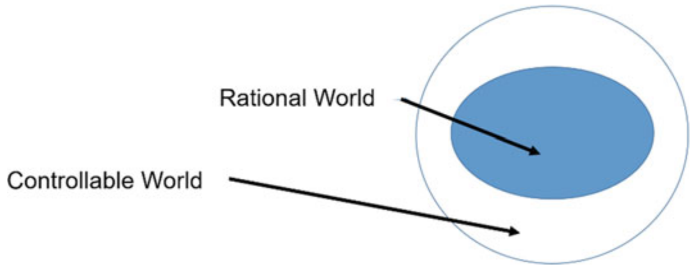



**Fig. 1.2** Rational world and controllable world

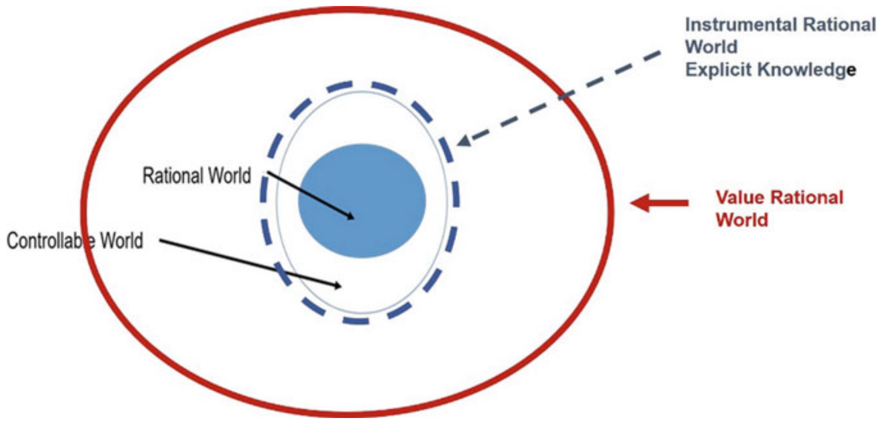



**Fig. 1.3** Instrumental rational world and value rational world

diversification and personalization. In other words, we will discuss why we have to explore the value rational world beyond the instrumental rational world (Fig. 1.3).

## 1.2 Emotion

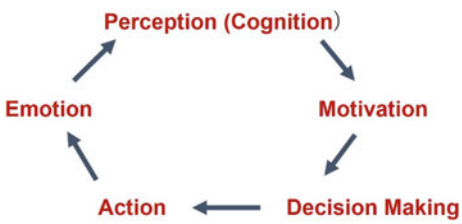
Emotion originates from the Latin word *e* (=ex=out) and *movere* (=move). Thus, it originally means "move out" or "act." Motivation also comes from the same Latin word *movere*. Thus, motivation and emotion are very deeply related.

Emotion constitutes the following cycle (Fig. 1.4).

Although value does not appear in this cycle explicitly, motivation is closely associated with value. We act because we think the action is valuable to us. And it also must be pointed out that motivation is closely associated with expectation. We perceive the environment and the situation, and we expect something. If we think this something is valuable, then we are motivated to move out or to act. But usually there are many choices including that of making no action. We evaluate or prioritize these choices, and if we believe one choice is more valuable than others, we make an action.

In our current engineering framework, determination of such a path plays a crucial role. Tremendous efforts are being paid to identify such an infallible path in

**Fig. 1.4** Perception–motivation–decision making–action–emotion cycle



current engineering. This is because reaching a clear-cut or clearly defined goal is believed to be most important.

## 1.3 Value

But we must remember value has much wider meanings. To borrow Simon's words, current engineering is trying to realize optimization. But today, environments and situations change very frequently and extensively and the number of variables is rapidly increasing, so it becomes increasingly difficult to optimize.

Therefore, as Simon suggests, we have to look for the way to satisfice ourselves. Thus, the importance of value rationality is rapidly increasing and we must make efforts to establish value rationality to cope with such frequent and extensive changes. Such changes promote diversification and personalization. In fact, it becomes quickly impossible to respond to rapidly diversifying customer requirements and to meet their personal expectations.

Another point we must take into consideration is that it is our human needs to actualize ourselves. The basic framework of current engineering was established, when changes were small and smooth. So, engineers could predict the future and they could foresee the operating conditions. Thus, machines were designed and produced to work best in such predictable operating conditions. But the operating conditions change frequently and extensively today due to the changes of the outside world. Thus, fast adaptability becomes crucially important. Therefore, if we borrow the traditional definition of value, the new definition can be redefined as

$$\text{Value} = \text{Adaptability}/(\text{time, cost}) \tag{1.2}$$

This means that if we can adapt to the environment and the situation in shorter time and with less cost, value will increase.

## 1.4 Objective Engineering and Subjective Engineering

We have noticed that the definition of value has changed. But we also should remember that the basic framework of our current engineering is objective. When we discuss environments and situations, we are discussing them objectively. But we must remember that our perception is very much subjective. We perceived them based on our past personal experiences and our own cognitive capabilities. In fact, perception and cognition vary widely from person to person. Even if we are in the same environment and under the same situation, what you perceive is different from those of others. Each person has his or her own environment and situation. We are motivated based on our own perceived environment and situation.

Let us take mountain climbing. For some people, if the mountain is very high, they look for some vehicles to take them up to the top. But others who are mountain climbers look for a difficult route to demonstrate their capabilities. In fact, challenge is the core and mainspring of all human activities. They would like to challenge.

So, the same mountain motivates people in very different ways.

Maslow [5] proposed Hierarchy of Human Needs (Fig. 1.5). And he pointed out self-actualization is the highest need of a human. As it is a matter of self, it naturally follows that the highest need varies from person to person.

About 40 years later, Ryan and Deci [6] proposed Self-Determination Theory. They pointed out the importance of intrinsic motivation and need to grow. There are two kinds of motivation: extrinsic and intrinsic. Extrinsic motivation is such an external reward as money. If money is given to the job, we are motivated to do that. But Ryan and Deci pointed out that we are not so happy if we are not motivated internally. If we would like to do the job, we feel very happy, even if we may not be paid enough or not at all. Thus, what matters with our feeling of happiness or emotional satisfaction is whether we are intrinsically motivated or not.

Another point they emphasized is our need to grow. That explains why mountain climbers would like to challenge a more and more difficult route (Fig. 1.6).

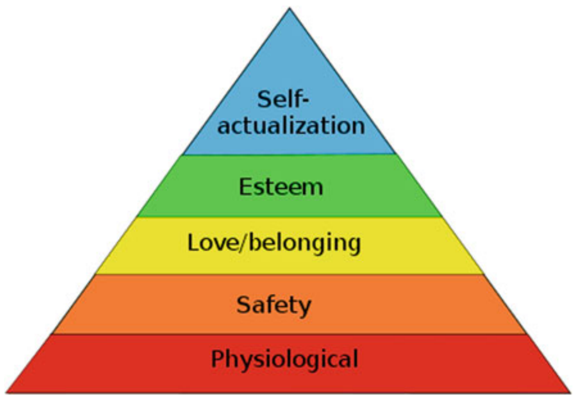



**Fig. 1.5** Maslow's hierarchy of human needs

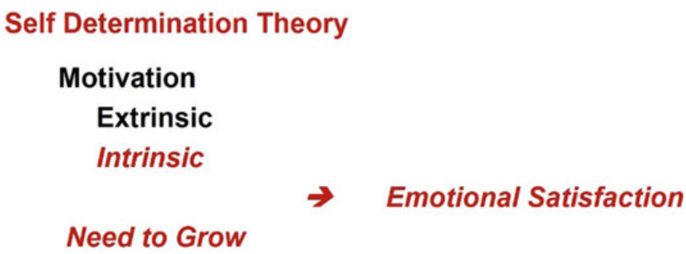



**Fig. 1.6** Self-determination theory

But current engineering treats us like a machine element. We are expected to act exactly the same way as we are told. Engineers expect reproducibility from us. In fact, most of the accidents called human errors are not really human errors. They happened because humans did not follow the instructions.

But in reality, especially in this era of frequent and extensive changes, only users know what is happening now. Users have to adapt to the changes quickly. Otherwise, they cannot survive.

In this age of sharp changes, which is mathematically nondifferentiable, we cannot predict the future. So, engineers cannot determine the operating conditions. It is only users who can understand the situation and adapt to it. Therefore, following instructions no longer works. We need to find ways by ourselves and make adequate decisions to adapt to the situation.

## 1.5 Expectation Management

Then, how can we find an adequate solution? As discussed above, in this age of an open world, where boundaries disappear and which is rapidly expanding, we cannot find an optimum solution. We have no other choice than to find a satisficing solution.

It should be stressed that value is deeply associated with expectation. When we perceive a thing, we expect something, and when we think that is valuable in our personal sense, then we are motivated. Thus, between perception and motivation, expectation comes in as follows (Fig. 1.7).

This flow is very much personal. Its content varies from person to person. The same mountain leads to different expectations. And even the same expectation leads to different motivations. That is why we feel happy when we make decisions ourselves, as Ryan and Deci pointed out. And when our expectations are fulfilled, we feel very happy. We actualized ourselves successfully.

Consideration of such human factors is almost neglected in current engineering framework. We have been regarded as something like a machine element. However, the quickly changing situations remind engineers of the importance of human factors. But they still stick to the idea that environments and situations are objective. They think our experience is the same if we are in the same environment and under the same situation. But as described earlier, our perception or cognition is very personal. So, we are experiencing personal environments and situations. Human factor discussion in such subjective or personal environment and situation is very few if any in engineering field. In fact, what we are doing in our daily life is we are looking for reason for action.

**Perception (Cognition) ➔Expectation ➔ Motivation**

**Fig. 1.7** Flow of perception–expectation–motivation

Expectation management is a key word in business world. It pays attention to this problem, but their interest is extrinsic motivation. How they can attract customers with their products. Discussion in business is naturally more focused on extrinsic motivation. However, it is without doubt that expectation management will increase its importance not only in business, but engineering world as well. What is important is value is related to expectation.

$$\text{Value} = \text{f}\,(\text{Expectation}) \tag{1.3}$$

Of course, expectation in expectation management in business is directly related to motivation. Business people would like to know what expectations their customers have and how they can motivate them to buy their products. Thus, their goals are identical. They do not care too much about the issue of personal perception (cognition). They study expectation and motivation. But, their job is to sell their products.

Our engineering discussion here about expectation management starts, however, from the fact that the world we are perceiving is personal and subjective. Our perceived world varies from person to person. So, it is personal all the way from Perception to Expectation, to Motivation, to Action, and finally to Emotion.

So, in this sense, the approach we are proposing here is very different from most of the current approaches. Mass customization and personalization is getting wide attention these days to tailor to the quickly diversifying customer requirements. But their discussion is how adeptly we can cope with the quickly diversifying customer requirements with the current engineering framework, and they do not discuss such a problem of subjective or personal perception.

Then, how can we build up such a personalized system? It is certainly impossible to develop a personalized and subjective engineering system that meets each personal expectation. Then, how can we develop a system that fits all and that still caters to such personality issue? In short, how can we create value on a personal basis but still maintain rationality, i.e., value rationality? This will be discussed in the next chapter Versatile Engineering.

## 1.6 Summary

This chapter points out that to cope with the rapidly expanding open world where changes are frequent and extensive and requirements are too much diversified, we need to step out of the traditional engineering framework of instrumental rationality or the world of explicit knowledge and move toward the world of value rationality, where values are evaluated on a personal basis and products and services are developed to cater to such personal values.

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# Chapter 2
# Versatile Engineering

**Shuichi Fukuda**

**Abstract** It is pointed out in Chap. 1 that to cope with the rapidly progressing diversification and frequent and extensive changes, we need to move from theoretically rational engineering to value rational engineering. In this chapter, we discuss what are needed to step forward towards this direction. Three major points are taken up: ambience, modularization and resilience. We have been paying most of our efforts to develop excellent functions for specific purposes. But it is impossible to take care of individual needs this way. Ambience is one possible solution. Just as we find a personally comfortable spot under sunlight, we can utilize ambience as we like and as we need. Modularization is attracting wide attention these days, but most of the discussion about it is made from the standpoint of product value. How we can reduce time and cost to produce a product that will meet diversifying needs or expectations from our customers. But from the point of value rational engineering, modularization is important because it turns processes into value creating activities. Thus, modularization is important in terms of process values for value rational engineering. Zweckrational or theoretical rational engineering shows us a clear-cut path to the goal. But in Wertrational or value rational engineering, we need to go forward by trials and errors. Thus, learning from failures becomes very important in value-oriented engineering. Therefore, the importance of resilience is stressed. In short, the transition from theoretically rational engineering to value-oriented engineering means we have to be more pragmatic in our engineering.

## 2.1 Introduction

We have discussed in Chap. 1 that it becomes increasingly difficult to cope with the rapidly increasing diversification and to adapt flexibly to the frequent and extensive changes if we stick to the traditional instrumental rationality.

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We have succeeded in expanding controllability beyond the rational world, because we managed to identify feature points in the system, which can be described explicitly.

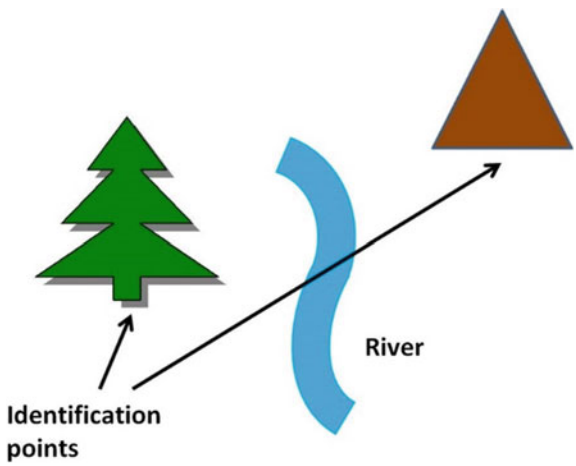
Let us explain by taking an example of identifying the name of a river. A river is always changing. So, if we look at the river itself, we will never be able to identify its name. But if we turn our eyes from the river, and we look around it, we find trees or mountains which do not change. These feature points lead us to the identification of the river (Fig. 2.1).

Let us take arc welding for example. Arc changes its state from gas to liquid and then to solid. There is no single governing equation that describes this state transition. If we could control arc, we could prevent thunder and lightning. There are many researches on arc, but its behaviour cannot be described. So, instead of focusing our attention on molten pool, we look around it and find feature points which can be rationally analysed and controlled. Thus, we can control arc, although we cannot predict its behaviour. Arc welding is, as everybody knows, used in many engineering structures. Engineering expanded its controllability this way. We were very clever so we could rationalize the system, although it involves such elements which do not follow rational rules. To put it another way, we succeeded in expanding explicit knowledge, beyond the rational world.

But environments and situations are quickly changing. They change more frequently and extensively and the nature of the change itself has changed. Changes yesterday were smooth so that they could be differentiated. Therefore, we could predict the future. But today changes are so sharp, and we cannot differentiate them. It means theoretically speaking we cannot predict the future (Fig. 2.2).

Michael Polanyi [1] pointed out that there are two kinds of knowledge: explicit and tacit. Explicit knowledge can be verbalized or can be expressed by equations. But tacit knowledge cannot. What traditional engineering pursued was how we can expand explicit knowledge world. Our challenges were successful until today.

**Fig. 2.1** Identification points



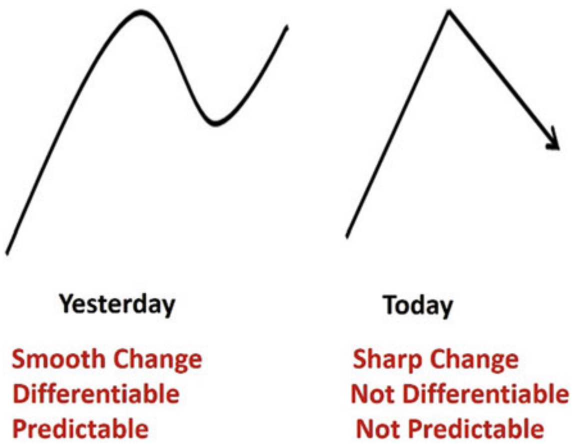



**Fig. 2.2** Changes of yesterday and today

But today, environments and situations change so frequently and extensively and we cannot find controllable feature points.

Bicycle riding is often taken up as an example of tacit knowledge. But in the case of bicycle riding, we still can manage to find feature points around us, although it is not easy.

But if it comes to swimming, water is always changing so we cannot find any feature points around us anymore. We have no other choice but to rely on our own sense of balancing or proprioception [2].

Until now, we have been observing the system from outside and identify the system and its controlling parameters. But this approach does not work in the case of swimming. We cannot identify the system and its controlling parameters at all, if we observe it from outside. We should be in the system or in the flow and learn how we can do the job. That is engineering tomorrow.

## 2.2 Human Motion Control

We have taken up swimming as an example of tacit knowledge, which current engineering approach does not work. So, let us first consider how motion control is different between machines and humans. As Nikolai Bernstein [3] pointed out, the difficulty of human motion control is its tremendous large degree of freedom. Figure 2.3 shows Bernstein's cyclogram. Near the target, human motion trajectories do not change. But apart from the target, human moves in many different ways.

In the case of machines, their trajectories are fixed so the same trajectory is repeated. But in the case of humans, their trajectories vary so extensively from action to action. This may be because they need to balance their bodies before doing the job. Therefore, it may not be too much to say that our motion control is just like

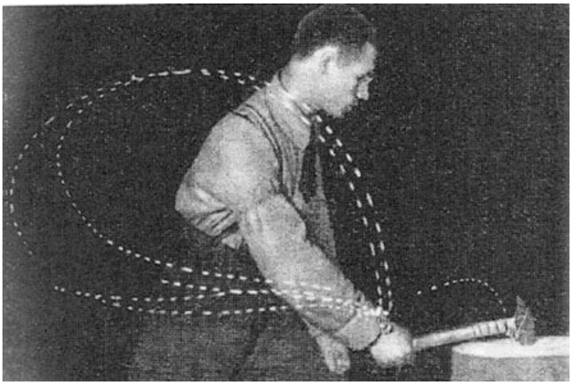


**Fig. 2.3** Bernstein's cyclogram

swimming. We do not find feature points to rationalize our motion trajectories, but instead we rely on our own sense of balancing.

To express this in another way, machine motion control is instrumentally rational, but human motion control is value rational. We do not care how we move, and we do not mind whether we can reproduce our behaviour. What we do care is whether we can hit the target or not, or in swimming, we can swim or not. We do not mind how beautiful we can behave to do the job. Achieving the goal is our first priority.

Thus, human motion control is goal-oriented. We are interested in what we achieve, not in how we do it. Human motion control is, therefore, a good example of tacit knowledge and value-oriented rationality. Achieving the goal means value. How we can get to the goal does not count much.

## 2.3 How Can We Move Towards Value Rational Engineering?

As pointed out many times, it is imminent for us to move towards value rational engineering beyond instrumentally rational engineering to expand our engineering in order to adapt to the drastically changing world. Let us discuss here how we can.

### *2.3.1 Ambient Engineering*

In 2014, Philips Lighting demonstrated ambient lighting at Frankfurter Messe. This surprised many people, including lighting designers. Until then, lighting has been considered as a tool to achieve a specific purpose. For example, reading lights are developed to assist us to read comfortably and with ease.

But their philosophy is very much different. Let us consider sunlight. Sunlight is shining everywhere, with no specific purpose. It creates ambience. And those who would like to bathe in the sun, they will go out. And those who would like to take a rest in the shadow, they will. Anybody can find a comfortable or a personally valuable spot in the sunlight. What Philips Lighting attempted to do was to provide such ambient lighting.

It must be remembered, however, that the word "ambient lighting" has been used for a long time before this demonstration. In photography, photographers often use ambient light, which is not prepared by them to take photographs. They pick up the spot which appeals to them. Thus, it is a matter of personal perception of the environment. Although the environment is the same, the spots where photographs are taken differ from photographer to photographer. In other words, how the environment is cut out in such a personal frame reflects the personality of a photographer.

These examples teach us a lesson. Even if we cannot develop engineering which can cater to each personal needs, we could develop such ambience. Then, people can find their emotionally satisfying personal space.

In a sense, common platform which is a buzzword today plays the same role. People can utilize the common platform as they like, and if they wish, they can add something, just like we wear accessories, when we dress up. Even if the dress may be the same, you look very much different and you feel different, when you put on different accessories.

### *2.3.2 Modularization*

Another approach would be modularization. This is also attracting wide attention these days. But most of the discussion about modularization is product-focused. We must remember that modularization has another advantage. Please consider Lego. Lego sells only blocks. But people enjoy putting them together to realize something. If we evaluate its value, then cost is minimum and putting them together into an object is great performance. So, its value is extremely high. What Lego taught us is there is another value in addition to product value. It is process value. We, engineers, forgot about process values. We have been paying our primary attention to the value of a final product alone (Fig. 2.4).

Most discussion about modularization is how we can develop a final product with less cost and time, but still it answers to the rapidly diversifying requirements. Very few discussions are made about how it will create process values.

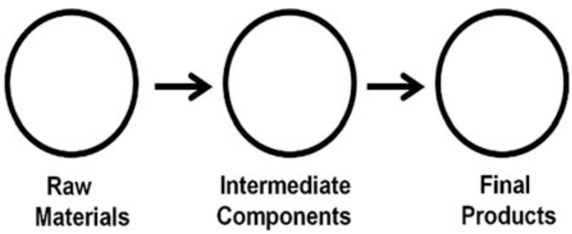
In Japan, flower arrangement and tea ceremonies are very popular. If we would like to enjoy beautiful flower arrangement or tasteful tea, it would be the best to ask experts to prepare them. Why we pay money to learn flower arrangements or tea ceremonies is we would like to enjoy the process. We pay money to the process, not to the final product we make.

**Fig. 2.4** Lego blocks

Additive manufacturing and 3D printing (AM3D) are attracting wide attention these days. But again, most of the discussion about them is final product-focused. They discuss how design and manufacturing can be made flexible and with less expertise. They have final product and current industrial framework on their minds. But as such movements as Maker indicate, these new technologies are expected to open door to the new engineering where process values are highly evaluated. People enjoy designing and manufacturing, just as Japanese do in flower arrangements. They are enjoying the process, and processes produce values. The vehicles are now quickly changing into EVs, and if EVs become prevalent, then, we do not need such complicated technologies, which are used in automotive industries today. EVs are modularized, so that many non-experts can design and manufacture. Then, the production of a vehicle itself will produce value. We have to note that the age is moving quickly from product value to process value, and engineering tomorrow must consider how we can produce value through processes.

Modularization is expected to change our engineering from product value-oriented to process value-oriented. And in fact, industry framework itself is expected to change from the current linear final product-based system (Fig. 2.5) to

**Fig. 2.5** Current industry framework



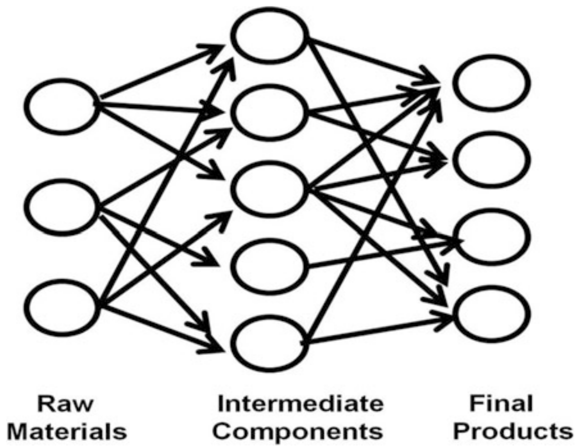



**Fig. 2.6** Future industry framework

intermediate component-based industry framework (Fig. 2.6). Then, even if intermediate components are designed and produced by experts, customers can still enjoy putting them together as they like and customize their final products. Thus, final products meet their expectations and they can enjoy the processes as well.

### *2.3.3 Versatility*

As pointed out, industry framework will be changing from the current final product-oriented to the intermediate component-based in order to cope with the frequently and extensively changing environments and situations and to meet the rapidly diversifying requirements and to enhance process values.

To express it another way, traditional industry framework has been tree-structured. But to increase flexibility and adaptability, it must be changed to network-structured (Fig. 2.7). In a tree structure (shown on the left), the output node is only one. Every node works to produce a better output. In traditional engineering, industry is focused on a final product. So, this tree structure works best because the goal is clear so that it will increase efficiency and it is easy to reduce cost.

But to increase flexibility and adaptability, industries have to produce many different products. Thus, a network structure (shown on the right) works best, because any node can be an output node. However, to increase its flexibility and adaptability more, the network needs to be adaptive. It must change its structure from case to case to adapt to the changes.

Knute Rockne, famous American football player and coach, left us the following words, “11 Best, Best 11”. What he meant by this word is “the best team cannot be made up with 11 best players. When 11 players play together as a team, it will become the best team”. And he demonstrated that this is true by bringing up University of Notre Dame to an ever-winning university.

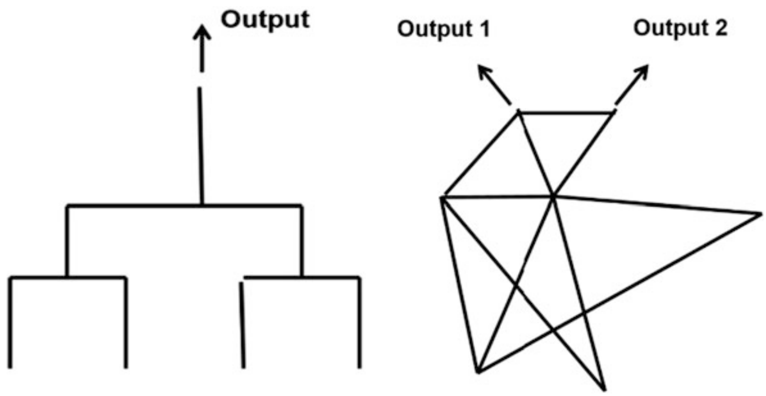


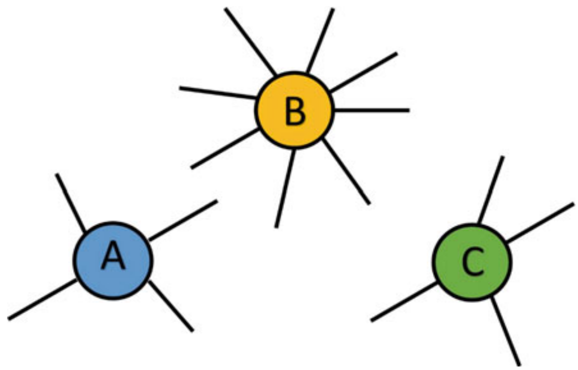

**Fig. 2.7** Tree and network

Franz Beckenbauer, famous footballer and manager, also introduced Libero system into soccer. Until then, each soccer player is expected to work best in his own position. But Beckenbauer realized that games come to change so frequently that a team cannot win if they play this way. Players must be more versatile and have to play together flexibly and adaptively as a team. His position was midfielder, and midfielders can see the whole game. They can understand how the game is changing and what formations are needed in the next step. So, he gave instructions or advice to other players how they can fight in another formation. Thus, he was called Der Kaiser. He introduced adaptable team working (network) into soccer.

Industrie 4.0 is attracting wide attention in engineering. This is also a change from 11 Best to Best 11. Until now, Germany is very famous for their excellent Meisters. But today, we need Best 11. So, Germany proposed Industrie 4.0. Its idea is to team up Mittelstand, small- and medium-sized enterprises (SMEs), to increase its global competitiveness. These SMEs may not be the best producer, but if they team up, they can produce best products flexibly and adaptively that meet rapidly diversifying customer expectations.

What is important for Best 11 is versatility. Figure 2.8 represents each SME as a node. What is important for Best 11 SMEs is to have many and different links, such

**Fig. 2.8** Versatile node



as shown as B. If each node (each SME) has many different links (different capabilities), then the possibility of teaming up as many different networks grows, so that flexibility and adaptability increase to a large extent.

Thus, versatility is the keyword in the next engineering.

### *2.3.4 Resilience*

Importance of versatility is emphasized. However, resilience is none the less important. Let us get back to the discussion of Zweckrationalitaet and Wertrationalitaet. Zweckrationalitaet is purpose-oriented, and it is means-ends rationality. It provides explanatory reasons or theoretical reasons, or it may be called evidential reasons. Wertrationalitaet, on the other hand, is very much practical. As pointed out earlier, it provides reasons for action, reasons for justifying our actions.

Zweckrationalitaet and Wertrationalitaet may be compared to railroad and voyage (Fig. 2.9).

In the case of railroad, we make decisions before we act and the goal is very clear. We decide which line or which train to take before we get on a train. Thus, means is directly related to the end and the process of getting to the goal is the same, if we select one choice. This is the same as in the case of machine motion.

In the case of voyage, even if we make a very good decision today, the weather might change suddenly tomorrow and the hurricane might be coming our way. Thus, in voyage, you need to set an immediate goal under the current situation and have to move ahead by trials and errors. In other words, we have to learn from failures to get to our final destination. To express it another way, resilience is needed.

In the case of railroad, we may be able to respond to the diversifying requirements, if we prepare many lines and trains. But no matter how many lines or trains we may be able to prepare, it is static. The framework does not change, or it may be called tactical.

In the case of voyage, it is strategic and dynamic. The situations change very frequently and extensively so we cannot prepare any fixed framework for our

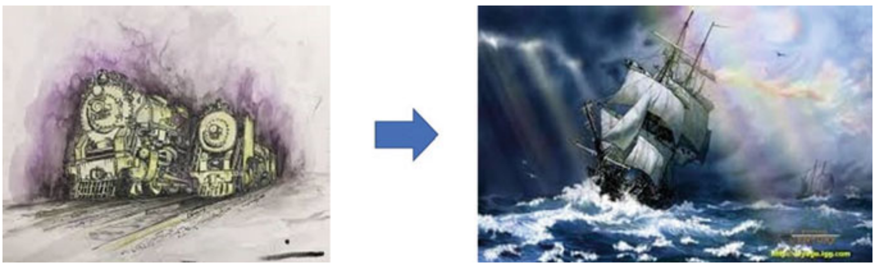


**Fig. 2.9** From railroad to voyage

actions. We have to observe the current situations and make decisions to adapt to or overcome the situation to move to the next step.

Railroad represents our traditional engineering, and voyage represents our future engineering. We need more practical or pragmatic engineering. Thus, learning from failures or trials and errors plays a most crucial role in our future engineering.

In our traditional engineering, we just keep on going forward and forward. Then, you can get to the goal faster. But what is called for in our future engineering is how we can go zigzagging but can find the right path to the goal. And there may be many paths. This is what we observe in human motion. Human moves in many different ways, but they know how to balance their bodies and can do the job after all.

Thus, Zweckrationalitaet can be compared to machine motion or railroad, and Wertrationalitaet can be compared to human motion or voyage. We have to remember that Zweckrationalitaet and Wertrationalitaet are deeply related. It may be said that Wertrationalitaet is a balancing of Zweckrationalitaet to respond to the current situation. Balancing is nothing other than resilience.

## 2.4 Summary

To cope with the rapidly progressing diversification and frequent and extensive changes, we need to move from theoretically rational engineering to value rational engineering.

Ambience, modularization and resilience play important roles for this change.

(1) Ambience

Traditionally, most of our efforts have been paid to develop excellent functions for specific purposes. But it is impossible to take care of individual needs or expectations this way. Ambience is one possible solution.

Just as we find a personally comfortable spot under sunlight, we can utilize ambience as we like and as we need.

(2) Modularization

Modularization is attracting wide attention these days, but most of the discussion about it is made from the standpoint of product value; that is, how we can reduce time and cost to produce a product that will meet diversifying needs or expectations. But from the point of value rational engineering, modularization is important because it turns processes into value creating activities.

Modularization is important in value rational engineering because it produces process values.

(3) Resilience

Zweckrational or theoretically rational engineering shows us a clear-cut path to the goal. But in Wertrational or value rational engineering, we need to go forward by trials and errors. Thus, learning from failures becomes very important in value-oriented engineering. To express it another way, the transition from theoretically rational engineering to value-oriented engineering implies we need to be more pragmatic in our engineering.

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# Chapter 3
# Traditional Japanese Housing: Hints for Future Engineering

**Shuichi Fukuda**

**Abstract** To adapt flexibly to the rapidly progressing diversification and to cope with the increasing frequent and extensive changes of environments and situations, we must move toward value-oriented engineering and engineering must increase its versatility to achieve this goal. In this chapter, we studied traditional Japanese housing with the hope that it will provide us with some hints to move in this direction. What we found is that ambience and personal emotional space are regarded as very important. The idea of personal emotional spaces is very unique, and it is expected that this idea will help us to develop our future value-oriented engineering.

## 3.1 Introduction

We have discussed Zweckrationalitaet and Wertrationalitaet proposed by Max Weber [1], and it is pointed out that to cope with the frequently and extensively changing world and with the rapidly increasing diversifying requirements from our customers, we need to move toward Wertrationalitaet engineering or value-oriented engineering.

In this chapter, we study traditional Japanese housing with a hope that it will provide some hints for our future engineering. Why we took up architecture as an example may be partly attributable to the words of Walter Gropius, founder of the Bauhaus school in Germany. He said, "Architecture begins where engineering ends." His words may indicate the difference between architecture and engineering. But no matter what he really meant, it motivated us to study traditional Japanese housing.

In the previous chapters, we have seen how engineering is changing from means-ends or purposive rationality to value-oriented rationality. Architecture may

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be defined as an activity to cut out a portion from natural space and to create environments humans need. What matters in architecture is how we cut out this space to suit to the purpose, and still this space maintains the connectivity with the outer world. Why we take up traditional Japanese housing is because Japanese are strongly conscious of how the inside and the outside are connected. Unlike Westerners, Japanese do not separate them from nature. Rather, how they can be fused into one is what Japanese have been pursuing traditionally.

In other words, Japanese are more interested in creating ambience than in dividing spaces for specific purposes. To express it another way, it may be said that Japanese are more interested in value rationality than theoretical rationality. Therefore, it is expected that we can learn something from them which would contribute to the development of value-oriented future engineering.

## 3.2 Ambience

As described in Sect. 3.1 Introduction, the underlying core idea of old Japanese housing is thought to be ambience-focused. We discussed ambience in relation to lighting in Chap. 2.

Let us take Shoji, Japanese paper windows or paper sliding doors for example. They penetrate outside light so we understand what is going on outside, although we are inside the house. If the wind is blowing, we know it is, because the shadows of leaves are swaying. And the light which comes in fades away gradually as it comes deeper inside. Further, paper windows or doors penetrate not only light, but also humidity, sound, and temperature, etc. Thus, Shoji may be called a holistic sensor. It senses almost all information, while most sensors today are developed to detect a particular signal (Fig. 3.1).

We should remember that cellulose nanofiber (CNF) is progressing very rapidly. In a sense, it is paper and its basic technology is the same as paper production. So, with the progress of such material engineering, windows or walls made of CNF

**Fig. 3.1** Shoji, paper window

**Fig. 3.2** Outside world allured them to the Japanese open, but covered verandah to enjoy talking

may work in the same way as Shoji and they would no longer separate inside and outside as they do today.

Current windows or doors separate the inside from the outside. But old Japanese houses do not. Therefore, we select the spot where we feel lighting, temperature, etc., are good to read or to relax. This is just what we do under the sunlight (Fig. 3.2).

James Jerome Gibson proposed Affordance Theory [2, 3]. He states that the world is perceived not only in terms of object shapes and spatial relationships, but also in terms of object possibilities for action [4]. He insists that perception of the environment leads to some course of action. This may be interpreted in emotional engineering that perception motives us and drives us to make some decisions to action as shown in Fig. 1.4. Therefore, it may be said that traditional Japanese housing paid more attention to creating such an affordance-rich environment than to dividing inside from outside and to securing spaces for specific purposes.

And we may not be going too far to say that affordance and ambience are deeply associated.

Charles Rennie Mackintosh, Scottish architect, was attracted by this ambience generating architecture design of Japan and he designed a tea house which is ambience-focused. Glasgow School of Art, which is one of his masterpieces, is full of such ambience cultures.

Japanese ambience may be compared to grayscale images in photography. Western culture, on the other hand, may be compared to black and white or color images. Grayscale images only have intensity (or lightness) values, while color has RGB values and even black and white is nothing other than reduction of color to black and white.

**Fig. 3.3** Japanese verandah provides an emotional space for enjoying conversations

## 3.3 Emotional Space

It would be better to describe such features of traditional Japanese housing as their eagerness to create emotional space. In fact, Japanese verandah plays a role of the common place. Visitors and home residents can talk sitting on the verandah without being conscious whether they are inside or outside the house. Japanese verandah is shared by visitors and home residents. Visitors do not feel that they are visiting home of others. There is no wall between the outside world and the world within. Japanese verandah provides an emotional space or environment for friendly conversations (Fig. 3.3).

It should be noted that in Affordance Theory, Gibson paid attention to objects, but in traditional Japanese housing, attention is paid to creating such an emotional space, not particular objects. It may be safely asserted that Japanese have been interested in creating emotional spaces.

## 3.4 Versatility

Another feature of traditional Japanese housing is its versatility. In Japanese housing, rooms are separated by Shoji, paper doors. This is also made of paper, but unlike paper windows, they are not transparent. But not only paper doors, but all doors in Japanese housing are sliding doors. This also indicates that Japanese do not distinguish between the inside and the outside. Sliding doors are rarely seen in Western architecture. Another point we should pay attention to is their sizes. As they are made of paper, they are light and they are of the size easy to take out and to bring to other places. So, we can change the room into a larger room or into smaller ones as we like. The size of a room varies with our change of emotion and with our needs. And the same room can be used for entertaining visitors or for sleeping. We use futon instead of a bed. So, we can take it away easily whenever it is necessary. And we use low dining tables so they can be put away after meals. And in addition

**Fig. 3.4** Typical traditional Japanese housing

for daily meals, we use low collapsible dining tables. These are the wisdom of old Japanese to secure versatility (Fig. 3.4).

It also must be added that tatami, straw mats, are developed with deep consideration to emotional space. Tatami has a length when we lay flat and its half length corresponds to our personal movement space. When we sit and move our bodies, its moving space is within the size of a half-length tatami, and when we are tired and would like to lie down flat, we can on a full-length tatami. Thus, the size of a tatami is determined based on our personal emotional space.

As their etymology indicates, motivation and emotion are deeply related. This personal space pay attention to the size of space which is deeply related to our motivation and the space of our following personal actions. Thus, the size of a tatami provides personal space where we can move as we are motivated and as we like. Therefore, it provides emotional satisfaction.

And the smallest size of a room is usually 4.5 tatamis. Quite interestingly enough, this is the same size as that of a cube of CAVE, an immersive VR environment. 4.5 tatami size rooms may come up as a result of observing that most of our movements are within this space size.

And it must also be added that the size of a tatami is developed for making it very easy to carry and for making production and repair easy. This is another consideration for emotion when we work.

Another feature of Japanese housing is there is no distinction between the column and the wall. In Western architecture, columns support loads. But in Japanese housing, columns and walls support loads equally. Therefore, in Western architecture, it is very difficult to renovate the house because we cannot move the columns freely. But it is quite easy in Japanese housing. We can take our columns or move them from one place to another without any trouble or difficulty. Thus, we can renovate the house as we like and as needed. It is easily observed from Fig. 3.5 that there is no distinction between columns and walls.

**Fig. 3.5** Tatamis, columns, and walls in traditional Japanese house

Thus, traditional Japanese housing pays full attention to portability, changeability, and flexibility.

## 3.5 Traditional Japanese House Design

Finally, let us look at the design of the traditional Japanese house, as a whole.

Water use section and heating section are separated, and as the entry is barrier-free, we can bring in foods, fuels, etc., very easily into kitchen. And it is interesting if we note that we can enjoy barbecue inside the house because a hearth is next to the kitchen so that we can enjoy cooking, dining, and talking without too much difficulty. In fact, a hearth provides an emotional space for relaxation.

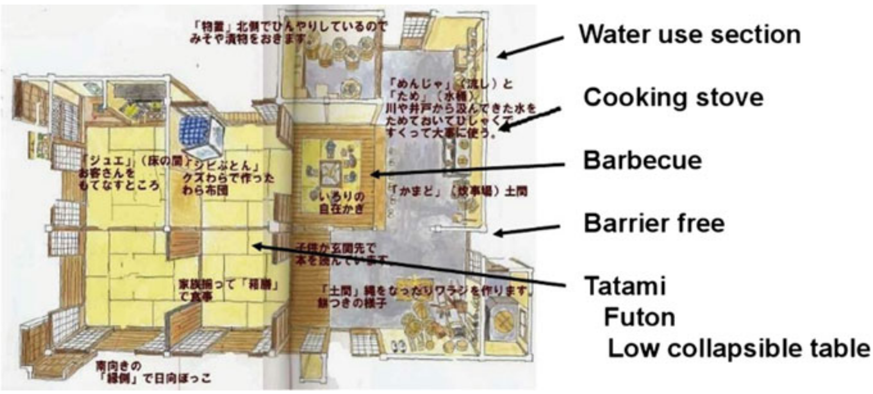


**Fig. 3.6** Floor plan of old Japanese house


**Fig. 3.7** Old Japanese house

As pointed in the above, old Japanese house is very flexible and changeable so that it adapts to the changes in environments, situations, and our emotions (Figs. 3.6, 3.7).

## 3.6 Feature of Japanese Culture

We have seen how flexible and adaptive old Japanese housing is. But this does not hold true for housing alone. It is the feature of Japanese culture. Japanese do not distinguish one thing from another. Japanese are fond of holistic thinking.

Let us take up Origami for example. We have to note that in Origami there is no distinction between 2 and 3 dimensions. Two- dimensional sheets are changed into three-dimensional objects. And at the time of starting Origami, it is an analog object, but it finishes as discrete elements or it starts from a continuum and ends as an assembly of discrete elements.

Origami is now a prerequisite for aeronautical and astronautical engineering for developing deployable structures. It also plays an important role in packaging. But we also have to remember it contributes very much to arts. Origami can be analyzed mathematically, but why it spreads so widely in Japan is not because it is mathematically interesting but because the process provides joy. So, Origami relates more to value-oriented rationality rather than to theoretical rationality (Fig. 3.8).

**Fig. 3.8** Origami (box, crane, and tree and snake, artworks of Vincent Floderer, French origami artist)

## 3.7 Summary

It is pointed out in Chaps. 1 and 2 that to cope flexibly and adaptively with the rapid diversification and with the increasing frequent and extensive changes of environments and situations, we must move toward value-oriented engineering and engineering must increase its versatility to achieve this goal.

In this chapter, we studied traditional Japanese housing with the hope that it will provide us with some hints for us to move in this direction. What we found is that it gives special weight to creating ambience and at the same time it also attaches importance to personal emotional space. In fact, it may not be too much to say that traditional Japanese housing are built up with modules of personal emotional spaces. Such an idea of emotional space modularization is expected to serve for the development of our future value-oriented engineering.

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# Chapter 4
# External Haptic Stimulus Biases Sensory Evaluation of Odor Impression

**Naoto Yamashita and Tetsuro Ogi**

**Abstract** Delivering a certain impression, perceived by consumers as a synthesis of multimodal stimuli of food product or beverages, is considered as a key driver to promote stable decision for repeated purchases of the product. In this research, we examined effects of tactile stimuli on taste and odor stimuli in order to enhance/weaken those impressions by external tactile stimulus. Results of two experiments are to be reported. In the first experiment, subjects were asked to evaluate impression of room odor, using a pencil with coarsely or slippery texture on its surface, which were considered to be irrelevant to the source of the room odor. Significant differences of evaluation scores between two conditions were observed with respect to several impressions. In the second experiment, thermal stimuli were presented on palm of subjects, together with sensory evaluation of odor impression. The result reveals that thermal stimulus biases sensory evaluation, as indicated in the first experiment. Those results indicate that perceived impression as a result of multisensory integration of taste and odor is biased by tactile stimuli, even if it is implicitly presented, and thus, tactile stimuli are capable for controlling perceived impression of taste and odor.

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## 4.1 Introduction

Consumers' decision-making in purchasing a certain consumer product can be classified into the following two categories: decision to trial the product and, successively, decision to purchase the product repeatedly [1, 2]. Promoting consumers' repeated purchase is important especially for the industries of durable consumer goods [3], because whether the product is able to survive in the market or not is mainly depends on consumers' repeated purchase. More precisely, the decision of repeated purchase is classified into the following two types. The first type of such decision is *non-stable decision*, which can be easily varied by the price, advertisement, and package design of the product. The second one is *stable decision*, where attitude formation to the product is inherited in the consumer itself and therefore such decision is considered to be stable overtime. In other words, stable decision is hardly influenced by the price, advertisement, and other external information of the product. Therefore, encouraging or promoting stable decision of the customer leads to their long-term purchase of the product. On the hand, an attitude to the product is formed depending on whether the product meets the taste or needs of the consumer [4]. More precisely, [2] pointed out the importance of psychological experience as a consumer needs to be satisfied, and *user experience* is considered to be the one of such experience, which is of great importance in today's product development [5]. ISO9241-210 defines user experience as "a person's perceptions and responses that result from the use or anticipated use of a product, system, or service." The style of product development/design which strongly emphasizes user experience as a starting point of development is called user experience design, and it is getting common in development of various kinds of products. In user experience design, developers/designers firstly define a target experience delivered by the consumers' use of (or anticipated use of) the product and the following product design depends on the target experience. Considering that satisfying [2] psychological experience is equivalent to delivering the user experience which costumers want, user experience design is effective strategy for promoting stable decision of repeated purchase of the product. In addition, regarding consumer goods with short cycles of purchase and consumption (e.g., food and beverages), user experience design is of greater importance compared to the other consumer products.

In this article, as a part of the user experience provided by the product, we consider emotional impression such as "luxury" or "refreshing feeling," for example. Those are called as "Kansei impression." Here, we address the following definition of emotional impression. In order to recognize the environment around the body, we receive various information from body sensation constituted by five modalities (taste, olfaction, tactile, audio, and visual) and interaction between those modalities. As a small example, consider the situation of viewing a picture by hand. Let $\boldsymbol{\alpha} \in \mathbb{R}^p$ be a $p$-dimensional vector of any physical quantity provided by the picture, weight of the picture, surface roughness, and RGB colors of each pixel, for example. Corresponding to $\boldsymbol{\alpha}$, let $\boldsymbol{\beta} \in \mathbb{R}^q$ be a $q$-dimensional vector whose elements are perceived psychological. We perceive $\boldsymbol{\alpha}$ from our sensory organ as an input from environment and successively transform $\boldsymbol{\alpha}$ to $\boldsymbol{\beta}$ as an image of environment. Therefore, $\boldsymbol{\alpha}$ is not necessarily identical to $\boldsymbol{\beta}$. For example, in the case of visual sense, an illusion might occur because the size or length as a physical quantity ($\boldsymbol{\alpha}$) does not match with the psychological quantity ($\boldsymbol{\beta}$) such as the perceived size and length. The size–weight illusion [6, 7] is known as such illusion. It is known that an illusion is mainly caused by sensory interaction between two or more different sensory modalities. We can write the relationship between $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ by using a function $f$: $\mathbb{R}^p \rightarrow \mathbb{R}^q$, as

$$\boldsymbol{\beta} = f(\boldsymbol{\alpha}). \tag{1.1}$$

For example, if the “mass” of an object is inputted as $\boldsymbol{\alpha}$, the function $f$ returns perceived “weight” as $\boldsymbol{\beta}$. Furthermore, let A $\boldsymbol{\gamma}$ be the vector that summarizes the features of the object such as “luxury” and “refreshing feeling” that cannot be evaluated only from the physical property of the object, which is experienced as a result of integrating physical quantities. It is described as

$$\boldsymbol{\gamma} = g(\boldsymbol{\beta}). \tag{1.2}$$

by using a function $g$: $\mathbb{R}^p \rightarrow \mathbb{R}^r$. $\boldsymbol{\gamma}$ is obtained by the transformation of $\boldsymbol{\beta}$ by the function $g$, and in that sense, $\boldsymbol{\gamma}$ can be considered as an mental interpretation of $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$. In this article, we define $\boldsymbol{\gamma}$ as a vector of emotional impressions of the object, which is produced by the two-step transformations denoted as $f$ and $g$.

In the food industry, particularly in the cigarette industry, the design of taste and flavor is of great importance in product development, i.e., the control of the taste of the cigarette such as processing of materials and blending, flavor development. In other words, determining the physical properties of products has accounted for the majority of product development. Therefore, when designing a user experience, which can be considered as a factor promoting repeated purchase of the product, taste, and aroma of products, olfactory stimulation is therefore used as a main operation factor. Considering the situation where consumers consume cigarettes, however, consumption of cigarettes is not just about acts that enjoy taste and aroma; consumers see the package before smoking, open it and crash the capsule while smoking if the product with the capsule in the filter part. Consumer experience consists of stimuli to various sensory modalities other than taste and olfaction. From this, it can be said that user experience of cigarettes needs to be designed by using the stimulus to all five senses including not only taste olfaction but also sense of tactile sense and audiovisual sense.

However, even if stimuli other than taste and olfactory are also considered in user experience design, there seems to be a limit to the approach to design the user experience with the physical property as an operation factor. In order to show that from the viewpoint of designing a user experience that meets the needs of consumers and above definition of the emotional impression, let us consider constructing physical properties $\boldsymbol{\alpha}$ in order to create an intended emotional impression $\boldsymbol{\gamma}$. First, the function $f$ is a function that converts the physical quantity input from the sensory organ to the psychological quantity, and therefore, it represents the human perception system. Therefore, this function does not change greatly by individual; most of it follows Weber's law. On the other hand, the function $g$ is considered as an interpretation of the psychological quantity; the experience and sensitivity of the individual are reflected to a large extent, and it is expected that the function varies depending on the individual. For example, when eating chocolate, some people feel "luxury" by integrating the "bitterness" and "gloss of the surface," while others who feel "luxurious" by integrating "bitterness" and "hardness" from their food experience. Accordingly, the process where an individual $i$ percepts physical property $\boldsymbol{\alpha}_j$ from the product $j$ and covert it to emotional impression $\boldsymbol{\gamma}_{ij}$ can be expressed as

$$\boldsymbol{\gamma}_{ij} = g_i(\boldsymbol{\beta}) = g_i\big(f\left(\boldsymbol{\alpha}_j\right)\big). \tag{1.3}$$

What is important here is that the emotional impression $\boldsymbol{\gamma}_{ij}$ is an integration of physical quantity and psychological quantity and that the function $g_i$ representing the relationship between the two is a function which is unique to the individual. Therefore, designing a product $j$ such that individual $i$ experiences the intended emotional impression $\boldsymbol{\gamma}_{ij}$ for the product $j$ needs to clarify the function $g_i$, which is peculiar to the individual, and it is expected to be extremely difficult. It also arises another difficulty that even if one can clarify $g_i$, we can not necessarily say that the product $j$ designed based on it can provide the intended emotional impression for another individual $k \neq i$. From the above discussion, it is considered that there is a limit to the approach to control the emotional impression felt for the product by using the physical property of the object as an operation factor.

Recent findings in human interface research or cognitive psychology have shown that higher-order information processing including evaluation of emotional impression is affected by incidental tactile stimulus. For example, Ackerman et al. [8] discuss the influence of incidental tactile stimuli on decision-making. They attached sentences printed on a paper to heavy clipboards or light clipboards and asked to evaluate emotional impression felt on the sentences. The results showed that the group that read sentences pasted on a heavy clipboard were likely to judge that they are more "serious" or "enthusiastic" for the writer of the sentence compared to the group that read the same sentence pasted on a light clipboard. Spence et al. [9] showed through experiments that the surface texture of cutlery and dishes such as spoons and forks will affect the emotional impression such as luxury feeling and liking. When using a cutlery such as a metal, subjects were likely to judge that food as more luxury compared to using a cutlery made of plastic. In the above researches, in order to control the emotional impression on a certain object, it is distinctive that they use tactile stimuli irrelevant to the object and modulate emotional impression on it, rather than changing its physical property itself. Therefore, to design an emotional impression as a user experience, an additional tactile stimulus can be used other than designing the physical property.

However, in order to design an emotional impression by using the effect of tactile stimulus, it is necessary to clarify the following two points. The first point is that it is necessary to confirm whether the effect of tactile stimuli is also valid for the impression of olfactory stimulus. The above-mentioned researches have examined the effect on sentence recognition and emotional impression on taste, and it is not clear whether the same effect can be seen also for emotional impression to olfactory stimulus. Therefore, first of all, it is necessary to verify through experiments whether the emotional impression varies, by presenting accompanying tactile stimulus when evaluating the emotional impression of taste olfactory stimulus. The second point is that if it is confirmed that the tactile stimulus biases the emotional impression of the olfactory stimulus, it is necessary to establish general rule of effect of tactile stimulation on emotional impression. This seems to be a useful finding for judging what type of tactile stimulus should be presented in order to control emotional impression on the product.

Based on the above discussion, we firstly confirmed that emotional impression on olfactory stimulus is biased by tactile stimulus through two experiments. Tactile pressure and vibration are received by mechanical receptors present subcutaneously such as Meissner's body, Pacinian corpuscle and are then projected to the primary or secondary somatosensory cortices via the thalamus [10]. These touch pressure sensation and vibration sense added with pain sensation and thermal sensation are called cutaneous sensation. In this research, for the reason that it can be presented by the haptic design of the product, effect of the tactile sensation stimuli (Experiment 1) and thermal stimuli (Experiment 2) accepted by these mechanical receptors are considered, and we quantitatively evaluated the influence of these two tactile stimuli on the impression on olfactory stimulation. In Experiment 1, the influence of the tactile sensation presented irrespective of the smell on the impression evaluation is considered. In Experiment 2, we evaluate the effect of thermal sensation on the impression of odor by simultaneously presenting thermal sensation to palm and odor. Furthermore, by integrating these results, we summarized the effect of tactile stimulation on the impression of taste/olfactory stimulation as a general rule, which contributes to tactile design aiming at controlling emotional impression to taste/odor stimulation. Through these, it is possible to design products so as to provide intended emotional impression with consumers, not by the approach by controlling physical characteristics of the product itself, already mentioning its limitations. In particular, in markets where more than 300 types of similar products exist, such as cigarettes, and differentiation among products is becoming difficult, whether a certain product can provide an emotional impression is a key factor to make the product different from other products in terms of discrimination.

## 4.2 Experiment 1: Effect of Texture on Sensory Evaluation of Odor Stimuli

In the first experiment, we examined the effect of incidental haptic stimuli on evaluation of emotional impression. Subjects were asked to evaluate impression of room odor, using a pencil with coarsely or slippery texture on its surface. Stimulus presented by the surface of the pencil is considered to be irrelevant to odor to be evaluated.

### 4.2.1 Method

As a stimulus for presenting tactile stimuli to the participants, experimental stimulus was prepared by applying a spray (stone-like splay white, Asahi Pen) that adds harsh texture to the surface of HB hexagonal pencil (Tombow 8900-HM, Tombow). In addition, as a control stimulus, a white spray (TS-26 Pure White, Tamiya) was applied to the same hexagonal pencil. The surface of the pencil coated with the white spray has the same white color as the spray which adds a harsh texture, but the tactile sensation is almost the same as before applying the spray. It should be noted that the dynamic friction coefficient and the static friction coefficient of the pencil surface were 1.045 and 0.570 for the pencil with a rough texture, and 1.232 and 0.513 for the pencil with the control stimulus, respectively. These pencils were left in a constant temperature reservoir kept at 35 °C for 24 h before the experiment in order to prevent the odor of the spray applied to the surface from affecting the evaluation. The texture of these pencils is shown in Fig. 4.1.

Frankincense essential oil (Seikatsu-no-ki) was used as an odor stimulus for the subject of emotional impression for the following reasons. If we evaluate smells that are easy to remember, such as foods and fruits, it is expected that the impression of the foods or fruits itself will be evaluated rather than the impression of those odor. Therefore, Frankincense essential oil was used as an odor stimulus having sufficient odor intensity when sprayed into the room and being hard to recall what smell was. Prior to the experiment, the essential oil was atomized and diffused into the aroma oil diffuser in a highly airtight sensory evaluation room for 15 min.

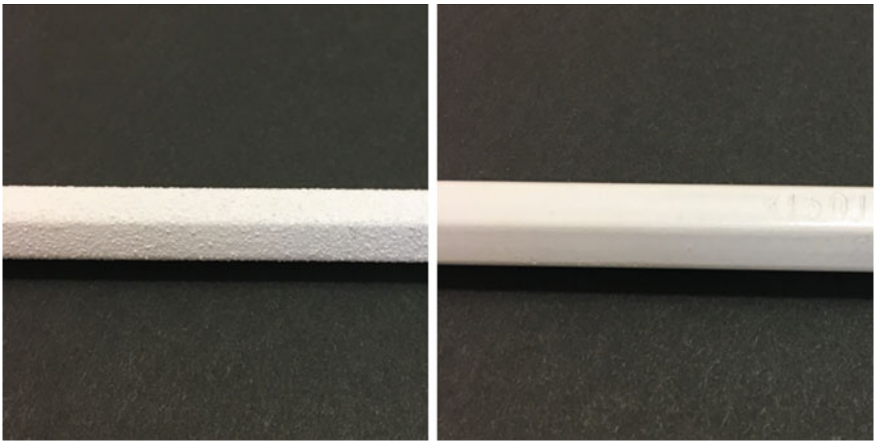

**Fig. 4.1** Pencils for experimental stimuli with harsh surface (left) and control stimuli (right)

The size of the sensory evaluation room was 17 $m^2$, and the room temperature was 22 °C. The experiment was started after the experimenter confirmed that odor was evenly distributed in the sensory evaluation room by spray diffusion for 15 min.

The participants were ten healthy male and female (seven males and three females), accustomed to the impression evaluation of odors. Also, the averaged age was 25.1 (s.d. = 1.73). Experimental conditions for presenting pencils of rough texture and control conditions for presenting control stimuli were conducted in different sessions, and the intervals were spaced more than three days between sessions. Each participant participated in both the experimental conditions and the control conditions, with counterbalanced order. In the sensory evaluation room, participants were sitting at regular intervals on a round table and experimented. At the same time, there were 1–3 participants participating in the experiment. From the beginning and the end of the experiment, the conversation between the experiment participants was not allowed.

Under the experimental condition, participants used a rough surface pencil and smoothed-surface pencil in control condition according to the following procedure. First of all, we placed the experiment participants in the sensory evaluation room and participants made the following tasks 1–3 with the given pencil. Each task was printed on a separate brochure, and each time the participant completed a task, experimenter distributed a questionnaire on which the next task was printed. As the first task, participants were required to fill in the Japanese-translated IPANAT [11], a questionnaire developed to measure the degree of positive mood and negative mood of participants through evaluation on meaningless character strings. In the experiment, it is necessary to present the odor and the tactile stimulus to the participants prior to the evaluation of the impression of the odor. Therefore, by filling in the IPANAT questionnaire, we presented smell and haptic stimuli before evaluation of room odor. In addition, the results of the IPANAT were also used to examine the influence of the degree of positive mood and negative mood on the emotional impression to the odor. As task 2, we asked to evaluate the impression of the odor of the room by the following 17 attributes; "Refreshing," "turbid," "elegant," "smooth," "complex," "unique," "thick," "supple," "nostalgic," "sharp," "energetic," "clean," "serious," "comfortable," "fierce," "coarse," and "natural." These attributes are cited from Higuchi et al. [12], Ferdenzi et al. [13] which examined attributes to describe odor. Also, in order to show that the effect of tactile sensation appears selectively for a specific impression, not all attributes, the term "serious" which seems to be inappropriate for evaluating the impression of odor [8] was also used. The evaluation was made on free-scale from "I do not feel it at all" to "I fell it very much" and on the scale, as an anchor to assist answers "I feel it slightly," "I feel it somewhat," "I feel it quite" are places spaced equally. Finally, as task 3, participants were asked to evaluate tactile sensation on pencil surface which they were using in the current session. Nagano et al. [14] review the dimensionality of haptic sensation that is often extracted in evaluation of texture. Here, among those evaluation dimensions, we employed the following six attributes for evaluating texture: "silky," "slippery," "moist," "smooth," "rough," and "nubby" with the same scale as the task 2. After completing all three tasks, participants were asked to leave the sensory evaluation room, and after sufficient ventilation, the essential oil was sprayed again for 15 min. With an interval of 1 day or more, participants evaluated the emotional impression of surface of the pencils by the same attributes used in the task 2, emotional evaluation of room odor.

## *4.2.2 Results*

### 4.2.2.1 IPANAT Score

Based on the results of Japanese IPANAT used in task 1, averaged value of evaluation for each mood term is obtained for each condition. Here, for *i*th participant ($i = 1,\ldots,10$) in *j*th condition ($j = 1$: experimental condition; 2: control condition), positive mood score $P_{ij}$ and $N_{ij}$ are given by

$$P_{ij} = 3^{-1}\Sigma_k p_{ijk}, N_{ij} = 3^{-1}\Sigma_k n_{ijk} \quad (1.4)$$

where $p_{ijk}$ and $n_{ijk}$ denote *k*th ($k = 1, 2, 3$) subscale score of positive and negative mood for *i*th participant in *j*th condition, respectively. Wilcoxon's sign rank test was conducted between slippery (control)/rough (experiment) conditions on each of the positive and the negative mood score. As a result, no significant difference (positive: $p = 0.333$; negative = 0.386) between the conditions was confirmed for both positive and negative mood scores, which indicates that the tactile stimulus presented to the participants did not bias on a mood difference in terms of positive or negative.

### 4.2.2.2 Emotional Impression of Room Odor

In order to investigate influence on the evaluation of emotional impression of room odor given by the difference in tactile stimuli on the surface of the pencils, scores between the conditions were tested using Wilcoxon's sign rank test. As a result, significant differences between the conditions were confirmed at "nostalgic" ($V$ (10) = 42, $p = 0.020$, $d = 0.953$) and "clean" ($V$ (10) = 5.5, $p = 0.043$, $d = -0.535$) at 5% level of significance and "unique" ($V$ (10) = 45.5, $p = 0.070$, $d = 0.395$) at 10% level. Figure 4.2 shows the average score and standard error for each attribute of emotional impression, where *d* stands for Cohen's *d* effect size [15].

In the above analysis, we examined the influence of tactile impressions individually for each of the impression attributes. However, rather than assuming that each impression word is individually influenced by tactile stimulus, there should be a smaller number of "combinations of impressions" behind multiple impression attributes, and they are biased by external tactile stimuli. By extracting such small number of combinations abstracting impression attributes, we can estimate the influence of tactile stimulus for impression other than those used in this experiment.

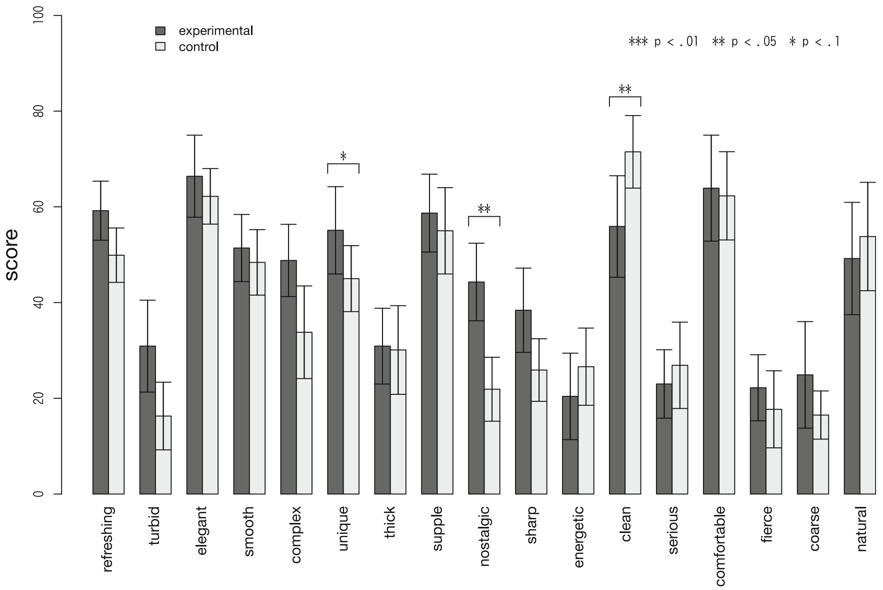


**Fig. 4.2** Averaged emotional impression scores in both conditions; error bar stands for standard error of average

Therefore, principal component analysis based on the correlation matrix was applied in order to extract such combinations, after row-wise standardization of the data matrix in order to eliminate scale difference of individual. The number of principal components was set at 3 according to the scree plot of eigenvalues, and 55.76% of variance of the data is explained by these components. Figure 4.3 shows averaged component scores.

With Fig. 4.3, for the second principal component, there exists a significant difference of scores between the conditions ($t(9) = 2.309$, $p = 0.046$). In addition to component loadings in Fig. 4.4, the second principal component corresponds to an impression attribute considered to be related to tactile stimulus such as "coarse," "complex," "turbid," "sharp," and "smooth." The second component can be interpreted as a combination of impression given by a rough texture by the following reasons: "coarse," "complex," and "turbid" loading on the component positively were considered as impressions felt by the rough texture presented under experimental condition; "smooth" which is considered to be given by slippery texture presented at control condition loads negatively on the second component. Therefore, combination of impression given by rough texture, corresponds to the second component, was highly felt at the experimental condition. Combining these results, it is considered that the emotional impression felt from the tactile stimuli is integrated to the emotional impression of odor, even if the texture presented by the surface of pencils are irrelevant to room odor.

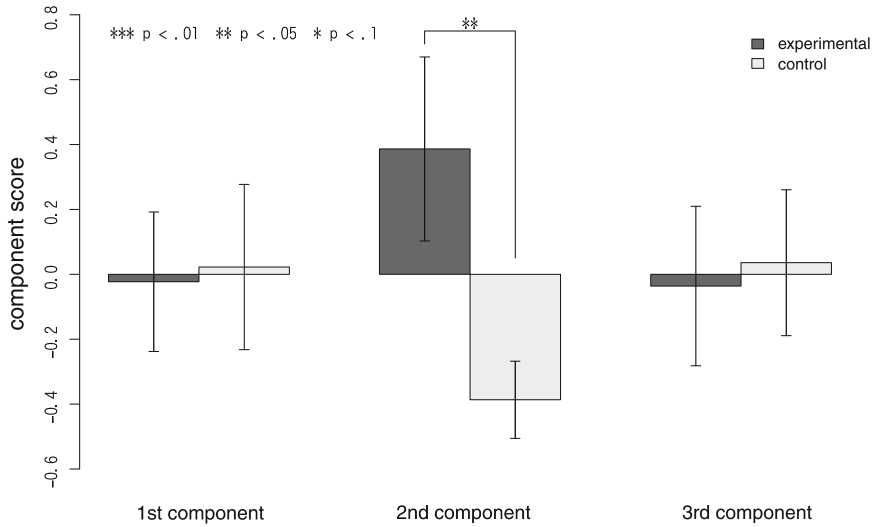


**Fig. 4.3** Averaged component scores in both conditions; error bar stands for standard error of average

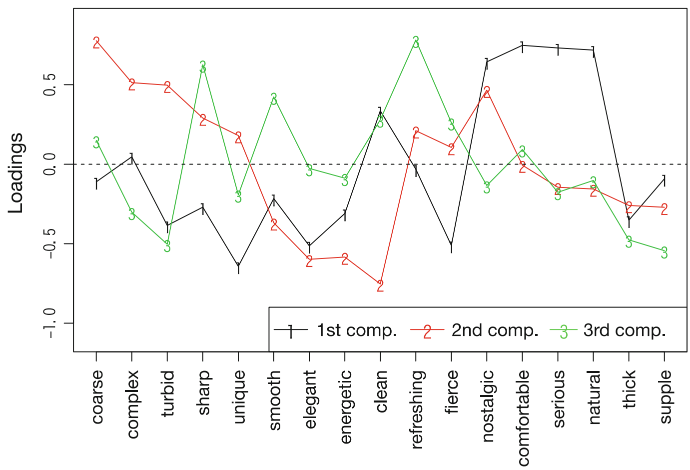


**Fig. 4.4** Component loadings for first to third principal components (order of attributes is rearranged)

#### 4.2.2.3 Evaluation of Texture

The average value of tactile evaluation performed in the task 3 is shown for each condition in Fig. 4.5. Wilcoxon's sign rank test was applied to each of attributes, and significant differences between the conditions are found at several attributes, as

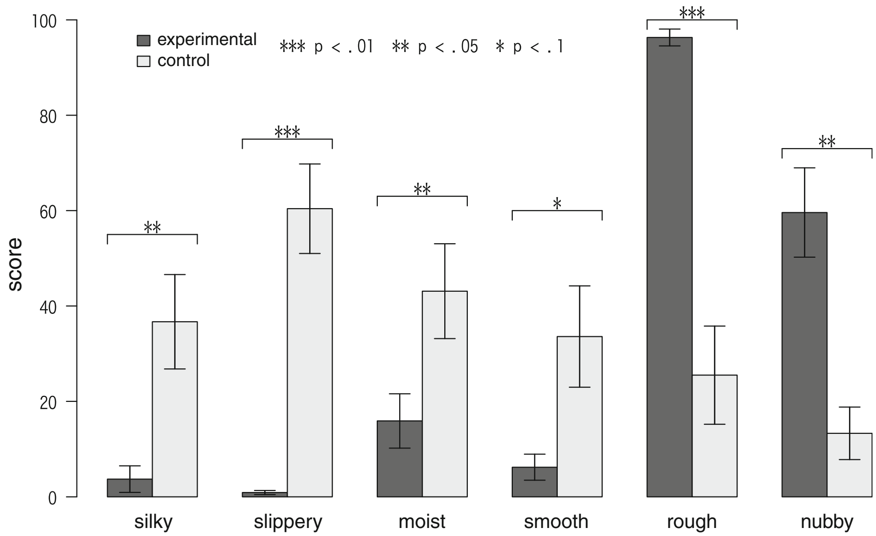


**Fig. 4.5** Averaged scores of texture evaluation of pencils; error bar stands for standard error of average

can be found in the figure. From this, it can be considered that the participants were given the intended tactile stimuli by using and touching the surface of the pencil. Also, as the error bars in the figure show, the variation in the evaluation of the participants is reasonably small, which indicates that all participants in the experiment are considered to feel almost the same feeling from the pencils though there are small individual differences within the same condition.

#### 4.2.2.4 Emotional Evaluation of Pencil Texture

The average value of tactile evaluation performed in task 3 is shown for each condition in Fig. 4.6. Wilcoxon sign rank test was applied to each of attributes, and significant differences between the conditions are found at "turbid" ($V(10) = 55$, $p = 0.002$, $d = 1.264$), "unique" ($V(10) = 53$, $p = 0.006$, $d = 1.725$), "energetic" ($V(10) = 53.5$, $p = 0.006$, $d = 1.535$), "coarse" ($V(10) = 55$, $p = 0.002$, $d = 4.030$), "complex" ($V(10) = 44$, $p = 0.008$, $d = 1.433$), and "sharp" ($V(10) = 52$, $p = 0.010$, $d = 1.535$) at 1% level of significance; "supple" ($V(10) = 6$, $p = 0.027$, $d = -1.165$) and "fierce" ($V(10) = 28$, $p = 0.017$, $d = 1.724$) at 5% level.

### *4.2.3 Discussion*

A significant difference between the conditions in the evaluation of emotional impression of room odor was observed at the attributes "unique," "nostalgic," and

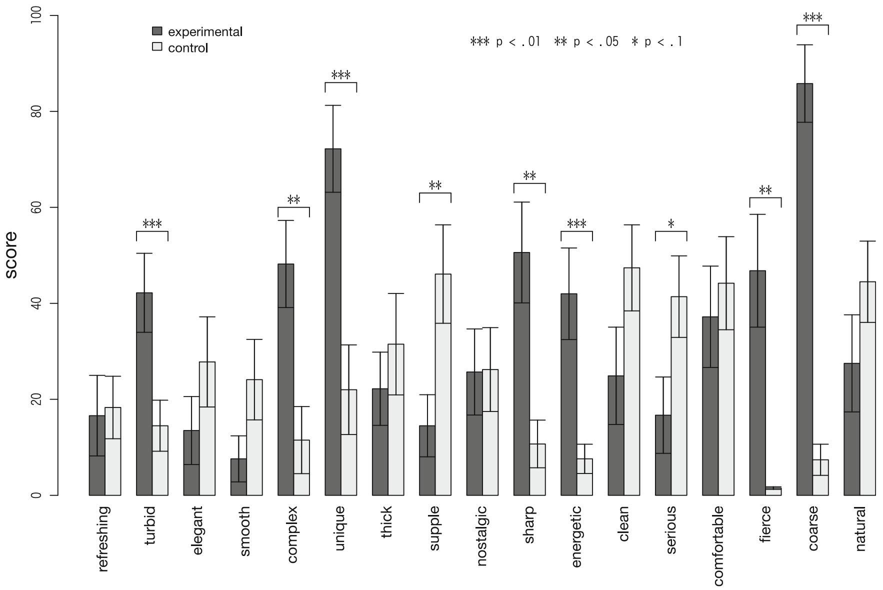


**Fig. 4.6** Averaged emotional impression scores in both conditions; error bar stands for standard error of average

"clean" due to the difference in the surface tactile sensation provided by the pencils. In addition, as a result of Japanese IPANAT, no statistically significant difference was confirmed in the positive/negative mood depending on the tactile sensation presented. It has been reported that mood of experiment participants influences decision-making [16–18]. In this experiment, it is considered that the tactile stimuli do not affect the mood of the participants, and the difference of the evaluation of impression is not caused by the difference in feeling given by the tactile stimuli. Furthermore, according to Fig. 4.5, it can be said that the participants felt all the intended feeling from the pencil surface, although there exists some individual difference. It is therefore considered that the tactile information given accompanying the emotional impression evaluation surely influences the emotional impression evaluation of odor. In addition, considering the results of the task 2 and task 4 shown in Figs. 4.2 and 4.5, respectively, it can be seen that the conditions in which higher evaluation values were observed are consistent with the impression of room odor and tactile sensation. The impression attribute "unique," for example, was highly evaluated under experimental conditions and also highly evaluated under the same conditions even in impression on tactile sensation. These results indicate that emotional impressions felt for the tactile information presented together with olfaction information were recognized as if they were attributed to the olfactory information, resulting in a difference in the impression evaluation between the conditions.

Principal component analysis was applied to extract a group of a few impression attributes existing behind the multiple impression attributes and investigate how much they are felt under experimental/control conditions by comparing component scores. As a result, three principal components were extracted in which the second component heavily loads the impressions “coarse,” “complex,” “turbid,” “sharp,” and “unique.” These attributes are in agreement with the impression felt more strongly to the tactile sensation presented under experimental conditions as shown in Fig. 4.6. This indicates that the second component can be interpreted as “a set of impressions felt for the rough texture.” Comparison of component scores reveals that the second component score is significantly higher in experimental condition. This suggests that when presented with a rough texture, the impression similar to the tactile stimuli is more strongly experienced and impression felt for tactile sensation was attributed to odor and experienced.

In this experiment, we examined the influence of tactile stimuli not attributable to the room odor, and therefore, it is considered that the participants recognized the presented tactile stimulus, that is, the tactile sensation of the pencil surface as being independent of the odor. As described above, it was confirmed that the impression felt for the tactile sensation was attributed to the odor. Therefore, it is suggested that the mechanism of recognition of emotional impression for a certain sensory input is as follows. When there are information inputs from a multiple of sensory modalities, the emotional impression felt with respect to these information is recognized in integrated manner for all modalities not parallel for each modality. Misattribution of impression therefore occurs in such situation. These results of this experiment are assumed as important suggestions on the tactile design of the surface of the product and the design of the interface to give the intended emotional impression, which is necessary for user experience design.

## 4.3 Experiment 2: Effect of Thermal Sensation on Sensory Evaluation of Odor Stimuli

In this experiment, influence of irrelevant thermal sensation on the evaluation of emotional impression of odor was examined.

### *4.3.1 Method*

The apparatus is composed of the following three components: Peltier controller with built-in Peltier element (VPE35-12-40S, VICS), a duralumin cylinder with a diameter of 25 mm and a height of 100 mm for presenting a thermal stimulus to the palm of participants, and a plastic container 25 mm in diameter and 50 mm in height for storing odorants. At the bottom of the cylinder, a duralumin plate of the same size as the Peltier element and a thickness of 5 mm is attached to the Peltier element. The temperature of the element surface is therefore transmitted from the element surface to the duralumin cylinder through the duralumin plate. A cedar board with a thickness of 5 mm was installed on the upper surface of the Peltier element for heat insulation. Also, in order to prevent the temperature of the duralumin cylinder from being transferred to the odorants and its physical properties and volatilization to be changed, a 5-mm-thick cedar plate is also installed between the cylinder and the plastic container. In order to eliminate the visual influence of the apparatus, the apparatus was covered with a dark curtain in the form that only the plastic container is visible.

Peppermint essential oil (Takasago Perfumery Industry) impregnated into a 5 mm × 10 mm paper was used as an odorant presented to the participants. And it is stored in the plastic container of the apparatus. The thermal stimulus is presented to the palm of participants by grasping the duralumin cylinder of the experimental apparatus, with the temperature of 38 °C in hot condition, 20 °C in cold condition, and 32 °C in control condition.

The participants were 12 healthy male and female (seven male, five female), and the averaged age was 28.4 years old (s.d. = 3.2).

The procedure of the experiment is as follows. After describing the purpose of the experiment and entering the consent form, in order to control the temperature of the palm, a non-dominant hand was placed on the hot plate holding the temperature at 32 °C with the palm down for 5 min. Then, in order to eliminate the influence of the auditory, participants were requested to wear a noise canceling headphone with white noise hearing. After confirming that the temperature of the upper end and the lower end of the duralumin cylinder was within the range of ± 0.5 °C from the temperature presented in the condition, participants were required to insert the hand of the non-dominant hand from the front side of the apparatus and grasp the duralumin cylinder. Then participants were requested to fill the following questionnaire by using a pencil with a dominant hand. First, in a state without smelling, coldness/warmth felt from the palm was evaluated in seven points scale from "very cold" to "very hot." Next, smelling the odorant from plastic containers, participants evaluated the impression felt from the odor by seven points scale from "I don't feel it at all" to "I feel it very much." We used the following 19 attributes for evaluation: "transparent," "refreshing" "cool," "exhilarating," "clear," "revitalizing," and "clean" which are thought to be felt on coolness; and "warm," "mild," "smooth," "energetic," "relaxed," "relieved," and "exciting" which are thought to be felt on warmth. "Thick," "bright," "dark," "comfortable," and "calm" which can be regarded as being irrelevant to warmth and coolness are also used. After the evaluation, participants pulled out the hand from the apparatus, took a 2 min break, then placed the palm of the non-dominant hand on the hot plate again kept at 32 °C for 5 min. Participants then proceeded another condition with a fresh odorant (Fig. 4.7).

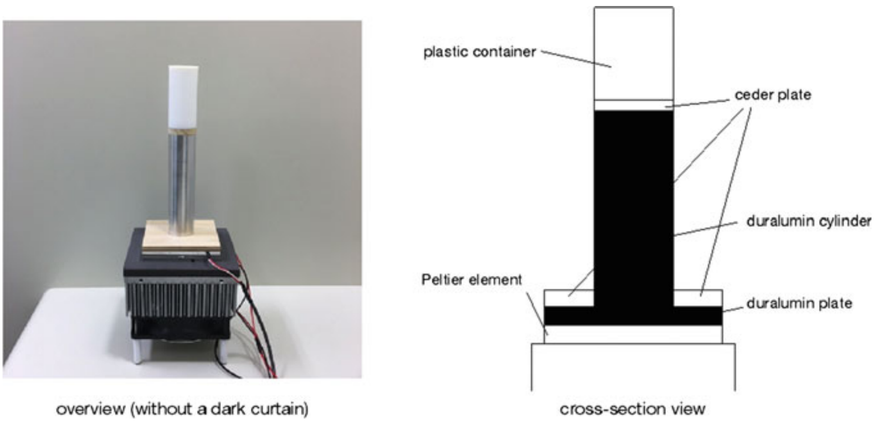


**Fig. 4.7** Experimental apparatus

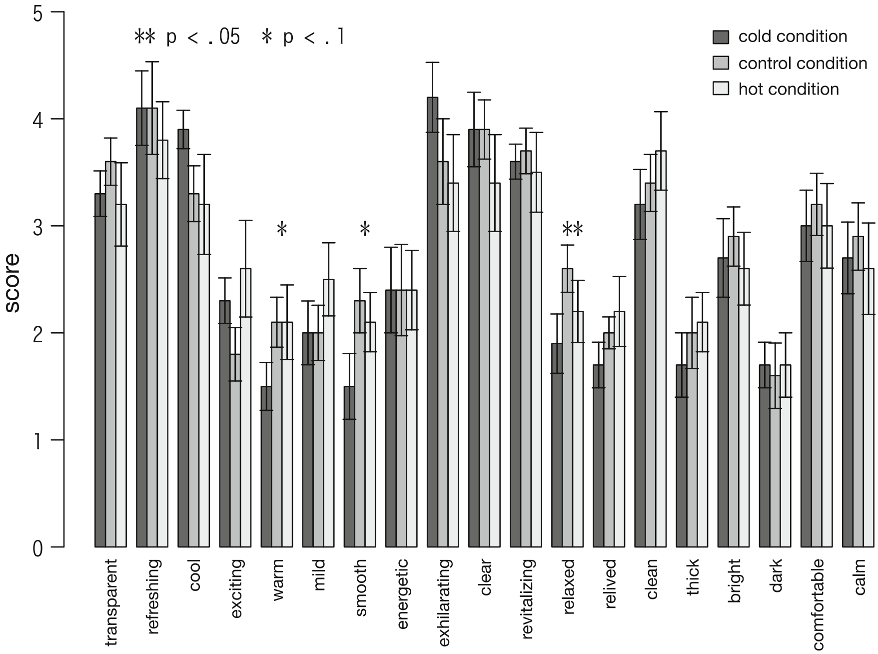


**Fig. 4.8** Averaged scores of emotional impression in cold/hot/control conditions. Error bar stands for standard error of average

## *4.3.2 Results*

Figure 4.8 shows the averaged impression score with respect to 19 attributes at hot/cold/control conditions. Mixed-ANOVA with the participants as a random effect and the conditions as a fixed effect was applied for each of the attributes in order to compare the evaluation between the conditions. As a result, significant effect of conditions was confirmed at "relaxed" ($F(2, 18) = 4.562$, $p = 0.025$) at 5% significant level and "warm" ($F(2, 18) = 3.115$, $p = 0.069$) and "smooth" ($F(2, 18) = 3.391$, $p = 0.056$) at 10% level. Tukey's multiple comparison was subsequently applied for these attributes, and the result reveals that the evaluation of "relaxed" impression is significantly lower in cold condition than in control condition ($p = 0.007$). And "warm" impression is lowest in the conditions (hot-cold: $p = 0.078$; control-cold: $p = 0.078$), and "smooth" impression is significantly lower in cold condition than in control condition ($p = 0.033$).

As in the Experiment 1, PCA is applied to the impression scores. Data matrix was composed by stacking subject × attributes matrices in three conditions, and number of components was set at 4 based on the scree criterion with 60.12% of variance explained. Figure 4.9 shows the averaged first, second, third, and fourth component scores in each condition. Clear difference between the cold condition and the hot condition can be seen at first component score. Result of ANOVA applied to the first component score with condition as a fixed factor shows a significant difference between the hot and cold conditions ($F(2, 33) = 3.491$, $p = 0.042$).

Figure 4.10 shows component loadings of 19 attributes. The first component heavily and positively loads on the attributes "cool," "exhilarating," "clear," "revitalizing," "transparent," and "refreshing" which are considered to be related to cold stimulus. Also, the component heavily and negatively loads on "mild," "smooth," "relaxed" "relived," and "warm" which are considered as impression felt on hot stimulus. The first component can be therefore interpreted as a set of impressions felt on cold sensation (Figs. 4.9 and 4.10).

### 4.3.3 Discussion

Similar to the first experiment, it is confirmed that thermal sensation, as well as texture, biases evaluation of emotional impression felt on olfactory stimulus. Also, the result of PCA indicates that the principal component, which can be interpreted as a "set of impressions felt on cold sensation," is highly felt in the condition where cold sensation is presented. It should be noted that these impression is considered to be related to thermal and somatosensory sensation presented by peppermint essential oil and its ingredient *L-menthol*. These results suggest that, as observed in the first experiment, the impression felt on thermal stimuli from the subjects' palm is integrated to the impression felt on the odor.

Ho et al. [19, 20] showed that integration of visual and thermal stimuli is Anti-Bayesian integration; contrast between two different modalities is highlighted. The results obtained in this example, however, suggest that olfactory and thermal

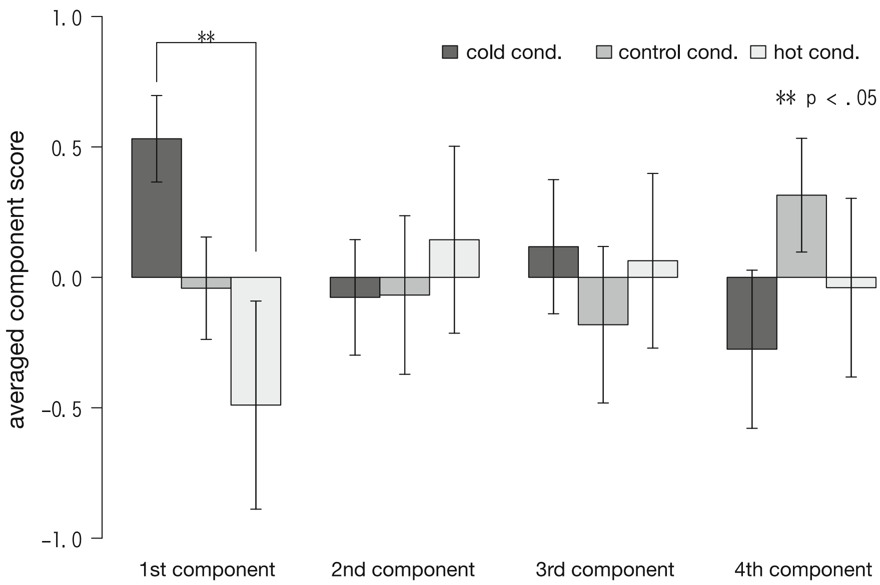


**Fig. 4.9** Averaged component scores in three conditions; error bar stands for standard error of average

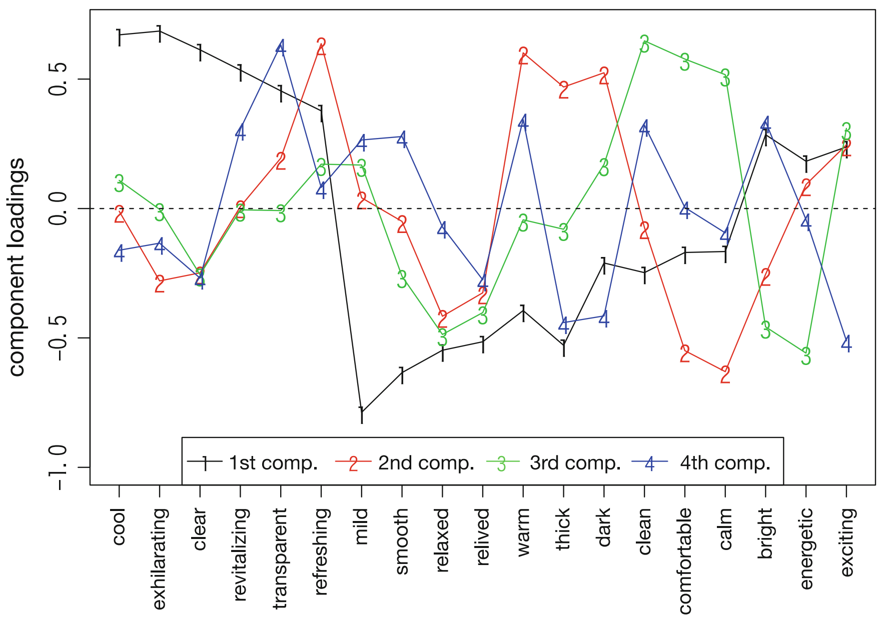


**Fig. 4.10** Component loadings for first to fourth principal components (order of attributes is rearranged)

stimuli are integrated as Bayesian manner. It can be said that, different from fundamental information processing considered in Ho et al.'s results, in higher-order information processing such as evaluation of impression, input from multi-modal is integrated as Bayesian manner.

## 4.4 Concluding Remarks

We considered the effect of haptic stimulus on emotional impression of olfactory stimuli by two experiments. The results of Experiment 1 and Experiment 2 are similar in the following point. Despite the subjects were instructed to evaluate the sensory impression on the odor, the impression of the incidentally presented tactile stimulus is experienced as an emotional impression of odor. It seems that there exists a common mechanism that the haptic stimulus influences the cognition of emotional impression in these two experimental results, and the mechanism is thought to be as follows.

Suppose that the situation where the haptic stimuli $T$ is incidentally presented at evaluation of emotional impression of the odor $O$. In the first experiment, $O$ and $T$ stand for Frankincense essential oil and the texture of the pencil. Here, consider that the emotional impression $A$ is felt on the odor $O$ itself and also the impression $B$ is felt on $T$. The results of two experiment suggest that when $O$ and $T$ are simultaneously presented and evaluation of impression on $O$ is required, the impression felt on $O$ is not only $A$ but also $B$. In other words, when we recognize the impression of $A$ and $B$ are felt from different stimuli, at least for the combination of olfaction and haptic stimulus presented in these experiment, it is suggested that we cannot clearly distinguish the source of these impression. As can be seen in size–weight illusion, inputs from two or more different modalities are integrated at information processing stage. Therefore, since the emotional impression as a result of higher-order processing is the result of integration of multimodal inputs, it is reasonable to assume the difficulty in orienting the source of different impressions.

At the same time, this suggests that impression of a certain haptic sensation $B$ can be "added" to the impression of olfactory sensation $A$, by simultaneously presenting the haptic sensation. In addition, as suggested from the experiments, contextual correspondence between the source of $A$ and $B$, $O$ and $T$, is not always necessary. We call this as "additive rule" of emotional impression.

The additive rule of emotional impression has an important implication for user experience design. As mentioned in the first section, user experience design, especially in the development of cigarettes, is not accomplished by optimizing taste and olfactory stimuli. The additive rule suggests that haptic sensation, presented by texture of package and cigarette, for example, can use another tool for controlling emotional impression felt on the taste and olfaction of the product. As a result, it is possible to design a product that can surely provide an emotional of impression desired by consumers. This implication is not limited for cigarettes, and considered to be available for other consumer products, which facilitates more flexible product design for controlling emotional impression and the following user experience.

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# Chapter 5
# The Selfish Brain: What Matters Is My Body, not Yours?

**Yoshiaki Kikuchi and Madoka Noriuchi**

**Abstract** Our behavioral response to our own crisis situations activates an automatic neural mechanism for protecting ourselves, while our response to others' crisis situations is not always toward saving them. That is, this automatic neural mechanism is implemented in our brain essentially for protecting not others, but the self, based on a biological principle. In this regard, it can be said that we have a type of Selfish Brain mechanism, which works primarily for protecting the self. Here, we focused on bodily unstable situations, and investigated whether the Selfish Brain could be observed or not, by viewing these bodily unstable situations of the self and others, and comparing the neural and behavioral responses, based on a third-person perspective paradigm. We found significant brain activity specific to one's own bodily crisis, but no significant activity in others' crisis situations. These self-specific regions included the regions that would be activated during genuine unstable bodily states: the right parieto-insular vestibular cortex, inferior frontal junction, posterior insula, and parabrachial nucleus. These right-lateralized cortical and brainstem regions may mediate vestibular information processing for detection of vestibular anomalies, defensive motor responding (in which the necessary motor responses are automatically prepared/simulated to protect one's own body), and sympathetic activity, as a form of alarm response during whole-body instability. Furthermore, there were no significant differences between the self and others in terms of subjective feelings. These findings suggest that the Selfish Brain mechanism is integral to our brains, and it works unconsciously and automatically to resolve one's own crisis.

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## 5.1 The Selfish Brain

What do we do when we are falling? We protect our body from falling by automatically and promptly attempting to control our bodily balance. Then, what do we do when another individual is falling? We help the individual we like, but are less likely to help the individual we dislike. Thus, our behavioral response to our own crisis situations activates the automatic neural mechanism for protecting ourselves, while our response to others' crisis situations is not always toward saving them. That is, this automatic neural mechanism is implemented in our brain for protecting not others, but rather the self, probably based on a biological principle. In this regard, it can be said that we have a type of Selfish Brain mechanism that works primarily for protecting the self. Thus, our behavioral and brain responses differ, depending on whether the threatening situation involves the self or others, and this situation is visually based on a first-person perspective. In fact, we can, of course, easily see other individuals, but we cannot see ourselves without a mirror, and this seems to be a very strong perceptual restraint. Although the first-person perspective is one of the most important factors for the self–other distinctions, it may be true that this viewpoint is also a confounding factor for observing the true self–other difference in brain activity based on visual recognition paradigms. We therefore considered that such factors could be excluded by using a third-person perspective paradigm, in which each participant could see his own body in crisis situations from the same perspective as the crisis situations of others, and the true self–other differences would be depicted as differences in the brain and behavioral responses, if it exists. Based on these considerations, we considered bodily unstable situations as a crisis situation, and investigated whether the Selfish Brain could be observed, by viewing bodily unstable situations involving the self and those involving others, and comparing the neural and behavioral responses, based on the third-person perspective recognition paradigm.

## 5.2 The Third-Person Perspective Recognition Paradigm

Thirteen right-handed healthy male participants (mean age = 24.7 ± 4.3 years) took part in the experiment. The stimuli were video clips of the participants' own bodies, as well as those of four other unfamiliar individuals, across three different conditions: statically stable (SS), dynamically stable (DS), and dynamically unstable (DU). Each participant was instructed to stand and maintain their balance on three types of wooden balance boards with two quadrangular pillars (SS), two round pillars (DS), and one round pillar (DU) (Fig. 5.1). In the DS condition, the board was moved horizontally at cycles of about 0.27 ± 0.03 Hz and with a range of about 10 cm. In the DU condition, the participant was instructed to keep the board horizontal as much as possible. Clips depicting the self were identified as such using a white mark positioned to the right above the image (Fig. 5.1). Here,

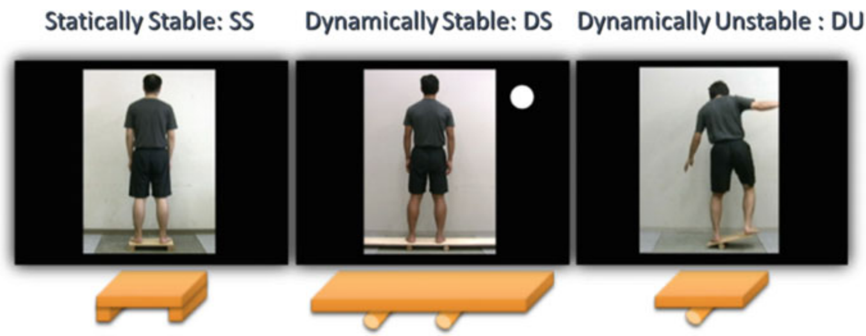


**Fig. 5.1** Three types of wooden balance boards used in the present experiment. The participant was instructed to stand and maintain his balance on three types of wooden balance boards: two quadrangular pillars (statically stable) (left), two round pillars (dynamically stable) (middle), and one round pillar (dynamically unstable) (right). A white circle was marked on the right above the self-clip

we defined "body instability," or the unstable components of whole-body movements, as the differential visual information based on the subtraction of DS (predictable and stable movements) from DU (unpredictable and unstable movements).

We contrasted brain activity during the DU and DS conditions separately for self and others (Self DU vs. Self DS, Others DU vs. Others DS) to investigate the neural basis of visual information processing of body instability, and these contrasts were also directly compared (Self [DU vs. DS] vs. Others [DU vs. DS]) to investigate self-specific neural processes related to body instability. In addition, here, we defined the "self-specific neural activity" related to body instability as follows: the activity in which it is significantly activated for the contrast of Self (DU vs. DS) versus Others (DU vs. DS), and the averaged eigenvariates in the spherical region of interest (ROI; radius 5 mm) centered at each cluster, showing significant activity in the above contrast is positive (activation) in the contrast of Self (DU vs. DS).

## 5.3 Statistical Analysis of Subjective Ratings

After the fMRI scans, the participants were asked to rate their emotional state while viewing the sample video clips. Four items measuring aspects of motion patterns and six items assessing various aspects of emotion were administered as follows: "How much did you feel the body was unstable (body instability), stable (body stability), dynamic (dynamic state), or static (static state)?" and "How much did you feel anxious (anxiety), relieved (relief), in danger (danger), safe (safety), impatient (impatience), or calm (calmness)?" We used a five-point Likert scale for data collection ("not at all, 0" and "completely agree, 4"). A two-way repeated-measures ANOVA (2 performers $\times$ 3 conditions) were performed for each of the subjective ratings at $p < 0.01$. If the sphericity assumption was violated (significant results in

Mauchly's test of sphericity), degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity. Post hoc tests with Bonferroni correction for multiple comparisons were applied at $p < 0.01$. In addition, for each of the subjective ratings, the differential score between Self DU versus Self DS was compared with that for Others DU versus Others DS using paired *t*-tests ($p < 0.01$).

In the aspects of motion patterns (Fig. 5.2a), there were no significant interactions between the performer and condition, in the body instability, body stability, dynamic state, or static state. There were significant main effects of condition, in all the motion aspects (body instability, body stability, dynamic state, static state). There were no significant main effects of performer in the body instability, body stability, dynamic state, or static state. Multiple comparisons for subjective ratings of motion pattern indicated that participants felt more unstable and dynamic, as well as less stable and static, in the DU condition than in each of the DS and SS conditions, and in the DS than in the SS condition. Moreover, paired *t*-tests showed that there were no significant differences between the self and others for the DU versus DS contrast, in the body instability, body stability, dynamic state, or static state. In terms of emotion (Fig. 5.2b), there were no significant interactions between performer and condition, in the anxiety, relief, danger, safety, calmness, or impatience aspects. There were significant main effects of condition, in all the aspects of emotion (anxiety, relief, danger, safety, calmness, impatience). There were no

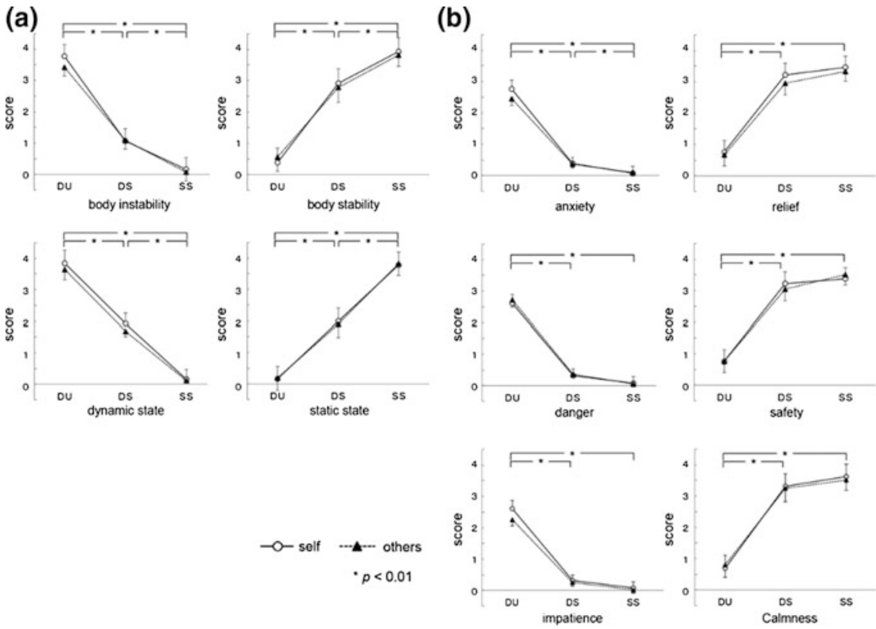


**Fig. 5.2** Subjective ratings of motion pattern (A) and emotion (B). There were significant main effects of conditions (DU, DS, and SS), and no significant main effects of performers. DU: dynamically unstable, DS: dynamically stable, SS: statically stable

significant main effects of performer in the relief, calmness, anxiety, danger, safety, or impatience aspects. Multiple comparisons for subjective ratings of emotion indicated that participants felt more anxious, in danger, and impatient, as well as less relieved, safe, and calm, in the DU condition than in each of the DS and SS conditions, and that they felt more anxious in the DS than in the SS conditions. Moreover, paired *t*-tests showed that there were no significant differences between the self and others for the DU versus DS contrast, in terms of anxiety, relief, danger, safety, impatience, or calmness aspects.

## 5.4 Neural Activity for Processing One's Own Body Instability

In the self-conditions (Self DU vs. Self DS), the right dorsal premotor cortex (PMd), parieto-insular vestibular cortex (PIVC)/temporo-parietal junction (TPJ), inferior parietal lobe (IPL), fusiform gyrus, putamen and caudate nucleus, left anterior supramarginal gyrus (aSMG), and the fusiform gyrus were significantly activated (Fig. 5.3).

In monkeys, the PIVC at the posterior end of the insula constitutes the core region of the vestibular cortex, as it contains many vestibular-driven neurons [2, 31, 32]. The PIVC is also considered to be the core region of the vestibular cortex in humans [25, 28, 32, 33] and receives disynaptic inputs from the vestibular complex via the thalamus [4, 12]. PIVC activity during vestibular stimulation is stronger in the right hemisphere in right-handed individuals [8], in concordance with our finding. In addition, right perisylvian areas including the IPL are also related to vestibular functioning in humans (caloric or galvanic) [25, 32, 33, 37] and the PIVC is also connected with the pulvinar area, suggesting possible routes for visual inputs pertaining to body instability to the vestibular cortex [32]. In addition, the right TPJ,

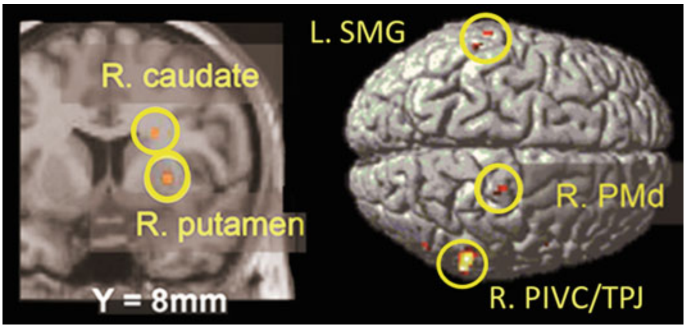


**Fig. 5.3** Brain regions significantly activated for the Self DU versus Self DS contrast. R: right, L: left, PMd: dorsal premotor area, PIVC: parieto-insular vestibular cortex, TPJ: temporo-parietal junction, SMG: supramarginal gyrus

which partially overlaps with the PIVC, receives somatosensory, visual, and vestibular inputs, plays a critical role in encoding spatial aspects of bodily self-consciousness [1], and is activated by any salient changes in sensory stimuli [26]. Thus, activity of this region may be related to information processing of the spatial aspects of highly salient and potentially dangerous bodily movements.

There was also significant activation of the right PMd (corresponding to the lower extremities and trunk), caudate, putamen, and left aSMG. These brain regions may be involved in automatically and rapidly transforming information regarding one's unstable movements from the visual allocentric space to the egocentric motor/ body spaces, based on one's own body schema [17, 32]. A meta-analysis of the functional neuroimaging studies of action representations [36] illustrates that extensive activity overlap exists between the motor-related brain areas during action observation, simulation, and execution. Moreover, the SMG is an important node in the network of fronto-parietal sensorimotor-related areas that represent limb movements [43]. The left SMG is particularly active during a variety of tasks involving tools [18, 36] and spatiotemporal control of skilled actions [34] and plays a key role in representing memories for skilled praxis [18, 23], suggesting that the left SMG underlies body schema representation. In addition, the left aSMG changes rapidly for optimization of responses to vestibular input during whole-body perturbations [40], suggesting that the body schema is flexible and can adapt to novel environments.

## 5.5 Neural Activity for Processing Others' Body Instability

The right EBA and left SPL were significantly activated in the Others DU versus Others DS contrast (Fig. 5.4), and these areas appear to be involved in processing others' body instability.

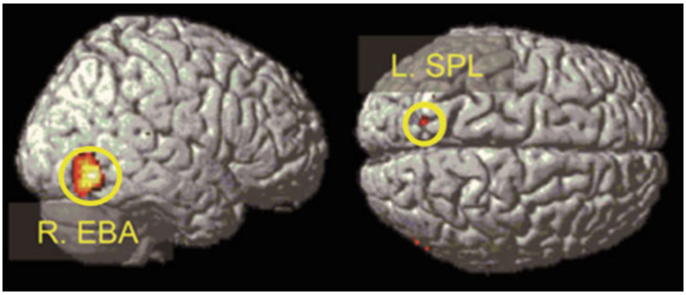


**Fig. 5.4** Brain regions significantly activated for the Others DU versus Others DS contrast. R: right, L: left, EBA: extrastriate body area, SPL: superior parietal lobe

The right EBA, which is activated strongly and selectively in response to static and dynamic images of human bodies and body parts [9, 27, 29], is activated to a greater extent by allocentric than by egocentric views [42, 45, 46] and responds more to impossible than possible movements [19]. This activity might be required for the visual analysis of others' body instability, in agreement with previous findings that the recognition of others is related to visual processing, whereas recognition of the self is more related to motor processes [30] (Fig. 5.5). In addition, left SPL activity is thought to be critical in the visual analysis of others' instability via the processing of specific body parts [11].

## 5.6 The Selfish Brain Discriminates the Self and Others

Based on these findings, the neural process of dealing with one's own body instability appears to consist mainly of the following three processes. First, there is a visual process for extracting dynamic body instability, in which body instability is extracted from visual representations of one's own whole-body movements. Second, there is a motor/body process for space transformation (from allocentric space to egocentric space), in which the instability components are interpreted as one's own unstable bodily state, based on one's own body schema. These two processes are associated with fusiform regions, the PMd, SMG, putamen, and caudate. Finally, there is a vestibular process in which degree of body instability is estimated via the PIVC. In contrast, the neural process of others' body instability involves only the visual information process (Fig. 5.5).

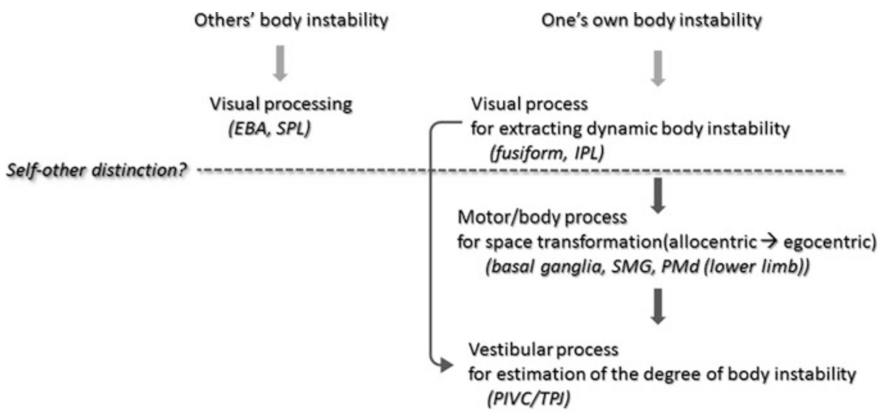


**Fig. 5.5** Comparison of neural processes by viewing one's own body instability and others' body instability. While the latter process involves only visual processes, the former consists of the motor/body and vestibular processes in addition to visual processes

## 5.7 Brain Regions Constituting the Selfish Brain

As shown in Fig. 5.6, the self-specific activity was found in the right rostral lateral prefrontal cortex (RLPFC), inferior frontal junction/ventral premotor cortex (IFJ/PMv), posterior insular cortex, and parabrachial nucleus (PBN), and the left lingual, fusiform and parahippocampal regions. Among the above brain regions, the IFJ/PMv, posterior insula, and PBN were considered to be the possible regions specifically corresponding to genuine bodily instability, based on previous studies. In contrast, there was no significant brain activity specific to the instability of others.

Activation of the right PBN and posterior insula, both of which are related to homeostatic processes and survival, was observed during the processing of one's own bodily instability. The communication between vestibular nuclei and the PBN is bidirectional, suggesting that the discharge of some vestibular nucleus neurons may present contextual information regarding the level of danger indicated by the incoming gravito-inertial information [44]. The PBN contains cells that respond to body rotation and position relative to gravity, and it appears to be an important node in a primary network that processes convergent vestibular, somatic, and visceral information to mediate avoidance conditioning, anxiety, conditioned fear responses, and affective responses, including panic associated with falling [44]. The response properties of PBN units allow detection of anomalies in head stability control, as a

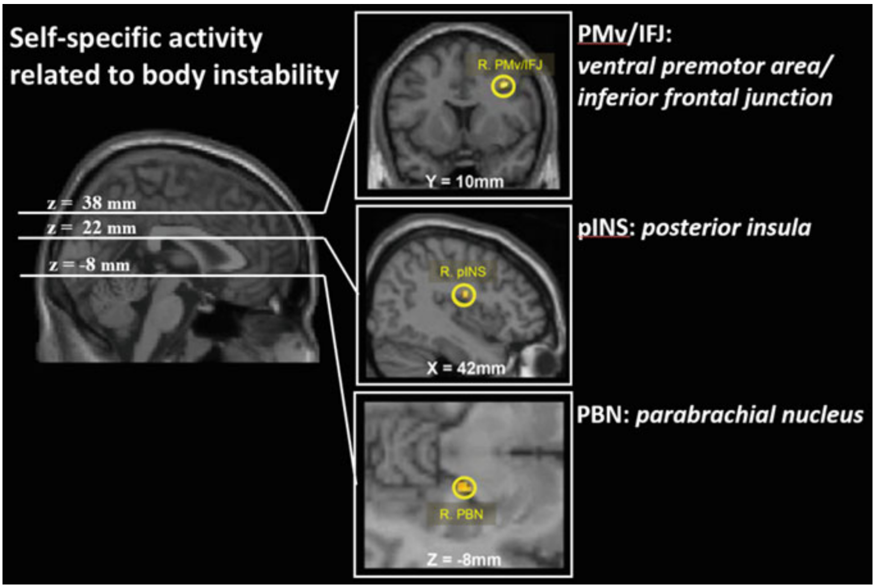


**Fig. 5.6** Self-specific brain activity in the DU versus DS contrast. The PMv/IFJ, pINS, and PBN were significantly activated for the Self (DU. DS) versus Others (DU. DS) contrast. PMv: ventral premotor area, IFJ: inferior frontal junction, PBN: parabrachial nucleus

consequence of body postural control loss relative to gravity [5]. Accordingly, self-specific PBN activity during the processing of one's own body instability might evoke such responses to dangerous departures from normal and stabilized movement trajectories. While the vestibular information for discriminating signals reflecting whole-body trajectory changes may contribute to either postural control or adaptive cardiovascular (e.g., vestibule/sympathetic) responses via descending PBN connections to the vestibular nuclei, medulla, and spinal cord [13, 20], inertial guidance monitoring may provide interoceptive information to ascending pathways, from the PBN ipsilaterally to the insula, via the thalamus.

The insular cortex is organized in a hierarchical caudal–rostral direction, whereby primary sensory inputs projecting to the posterior insula, including somatosensory, vestibular, and visceral inputs, are progressively elaborated and integrated across modalities in the middle insula [3, 45]. The insula differentiates sympathetic and parasympathetic activity [10, 39], and electrical stimulation of the right insular cortex elevates diastolic blood pressure and heart rate while stimulation of the left insula decreases heart rate [15, 16]. Sympathetic activity appears to be represented in the right hemisphere [15, 39]; thus, the observation of activation of the right PBN and posterior insula suggests strong sympathetic activity specifically in response to one's own body instability.

A meta-analysis has shown that IFJ/PMv [14] activity is associated with interpretation of potential threat-related stimuli [41, 48]. In particular, perceiving fear during dynamic body expression induces right PMv activity [49]. Moreover, electrical stimulation of the dorsal polysensory area of the PMv evokes a specific set of defensive movements (avoiding, protecting, and withdrawing) [35]. The centering movement of the eyes that occurs during defensive reactions is evoked by stimulation of the polysensory zone sites [6]. One major function of the polysensory neurons may be to monitor nearby potentially threatening objects and to coordinate complex movements in order to protect the body surface from those objects, implicating involvement of the right IFJ/PMv in motor preparations/simulation for such defensive reactions to an impending bodily crisis.

In addition, previous studies have suggested that a defining function of the rostrolateral prefrontal cortex (RLPFC) is metacognitive processing [7] or the process of reflecting upon one's own mental contents [21, 22, 24, 38]. In the present study, our participants were supine in the MRI scanner and viewed videos of themselves and of others making potentially unstable and dangerous movements. Metacognitive processing might be required for processing one's own movements, but not those of others. Additionally, the RLPFC is involved in motor learning, such that significant increases in gray matter volume and decreases in fractional anisotropy were observed in the RLPFC following only two sessions of practice at a complex whole-body balancing task [40].

Based on these considerations, the self-specific neural processing of body instability consists mainly of three component processes: (1) a vestibular/interoceptive process, which is related to detection of vestibular anomalies and to sympathetic activity as a form of alarm response (the right PBN and posterior insula), (2) an automatic motor-response preparation process (right IFJ/PMv), in which the necessary motor responses are automatically prepared/simulated in the brain to ensure protection of one's own body, and (3) a metacognitive process (right RLPFC) for self-recognition from the third-person perspective view.

## 5.8 The Selfish Brain Is Critical for Survival

The present third-person perspective paradigm clearly showed the self-specific brain response to one's own bodily crisis, irrespective of whether the perspective was not true for the self. In addition, there were very clear differences in brain activity, irrespective of the lack of significant differences between the self and others in subjective feelings about the bodily crisis. These facts suggest that the Selfish Brain mechanism is inherent to our brains, and it works unconsciously and automatically to one's own crisis. In contrast, it is not automatically implemented for helping other individuals in a bodily crisis. Of course, we can help the individual through higher decision processes, depending on the situation. Moreover, these brain regions, showing self-specific activity, were the internal representation of one's own movements and associated interoceptive representations, which are essential for survival. In fact, this brain activity approximated that which occurs in response to in vivo experience of body instability (e.g., slipping suddenly and almost falling down). That is, the right PBN, posterior insula, and IFJ/PMv are activated during the genuine experience of an unstable bodily state, together with the right PIVC, which is involved in the degree of body instability estimates. Furthermore, all of the neural structures showed marked right dominance at both the cortical (PIVC, IFJ/PMv, and posterior insula) and brainstem (PBN) levels, with the latter being directly connected to the vestibular nerve and therefore comprising a

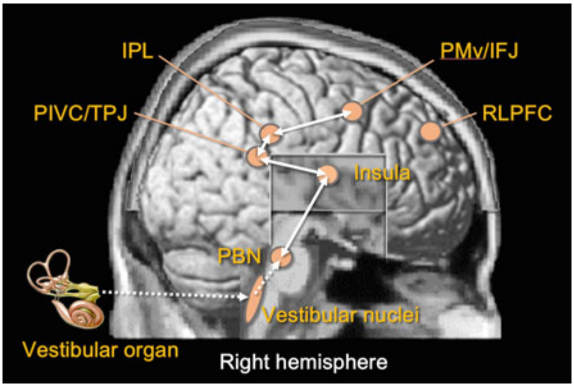


**Fig. 5.7** Selfish Brain responding to one's own bodily crisis. Vestibular information is conveyed to the PBN which connects bi-directionally with the posterior insula. The insula integrates various sensory information and interoceptive one. The inferior parietal regions including the PIVC and the PMv/IFJ process degree of the crisis and generate the necessary defensive motor response

very primitive neural structure (Fig. 5.7). This right dominance may be based on lateralization of homeostatic brain structures and functions, which has been evolutionarily driven by a preexisting behavioral and autonomic asymmetry that is present in all vertebrates [47].

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# Chapter 6
# Real-Time Kansei Analysis During Communication Using a Simplified EEG

**Tsutomu Sato, Yasue Mitsukura and Tetsuya Toma**

**Abstract** Many recent communication studies show meaningful results using biometric information measurements, such as body movement with accelerometers. However, most of them could not describe the reasons subjects showed body movement due to the lack of measurement abilities in real time. This background has made researchers expect real-time measurement methods of brain functions with superior time resolution. In this research, we succeeded in confirming a new method of communication analysis by using the Kansei Analyzer, a simplified electroencephalograph (EEG), which measures brain waves in real time to obtain internal information from a human being. The results of our two experiments show that it was possible to find quantitative changes when using this instrument. It is especially noteworthy that the concentration of one subject and the interest of another were synchronized, thanks to the superior time resolution. Brain wave measurements with an EEG have illustrated the quality of communication and the human relationship as constituent elements of communication in real time.

## 6.1 Introduction

In recent years, many methods for measuring communication have been established, and research using this has also produced a lot of results. A Business Microscope developed by Yano from Hitachi and research using this equipment are

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the examples [1–3]. However, many of them only record human behavior; internal information, like how human beings felt at that time, has hardly been obtained. Most studies use questionnaires to obtain such internal information, which is a posterior emotion, not accessed in real time. On the other hand, Kansei Analyzer, a simplified electroencephalogram (EEG), was developed as a means to obtain this internal information. This is not like fMRI and PET; it is so small that the subject's burden is not heavy. In this paper, we introduce experiments using this simplified EEG, Kansei Analyzer.

## 6.2 Kansei Analyzer

Kansei Analyzer, developed by our team member, Yasue Mitsukura [4], has been modeled into a headset as shown in Fig. 6.1. An electrode is placed at both the participant's left temple and left earlobe, and brain function is detected. This is converted into a signal and sent via Bluetooth to a tablet device (an iPad in this experiment). The signals are analyzed, and the emotions ("Kansei") listed below are measured on a scale of 1–100.

- Like
- Interest
- Concentration
- Calmness
- Stress.

75 s of calibration is done before the actual measurements are taken. There is no point in comparing EEG of different participants, as individual measurements can vary. By performing a calibration, we measure the brain activity at rest for each individual and take its maximum value to be 100 and minimum 0. These measurements are taken every second. The data can be saved in.csv format, so they can

**Fig. 6.1** Kansei Analyzer

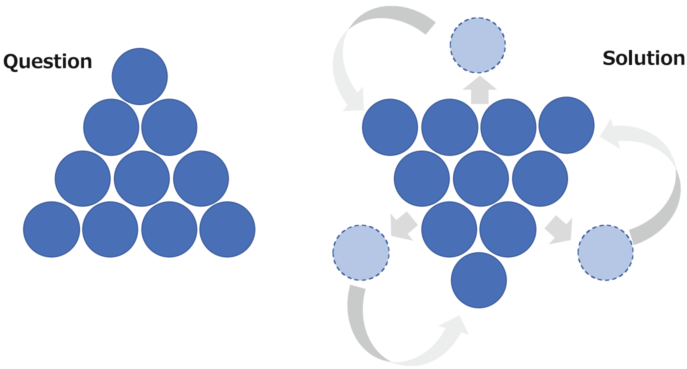


**Fig. 6.2** Question and solution of Question 3 in Experiment B

be analyzed on computers afterward. The reliability of this device has already been proved [5]. Moreover, many clients have been requesting and using the services provided by Dentsu Science Jam Inc., which incorporate the use of this device.

The word "Kansei" used in this report has not only been used in Japan but also used in many academic [6] and corporate settings internationally as well. Below are the defining criteria set by Akira Harada [7].

1. Subjective and impossible to explain the mechanisms
2. Innate characteristics and cognitive expression of knowledge and experiences
3. Interaction between intuition and intellect
4. Ability to intuitively react and judge
5. Imagination and creativity of the mind.

They are all criteria based on the inner workings of a human being, and it is believed that EEG can contribute to researches that involve them.

## 6.3 Experiment

In this section, two experiments using the Kansei Analyzer are introduced. By using the analyzer, we evaluated Kansei during communications between two subjects:

- Experiment A: free conversations
- Experiment B: conversation with an objective of problem-solving.

The specific methods of the experiments and results will be elaborated on in Table 6.1. The Kansei Analyzer was provided by Dentsu Science Jam Inc. Its use in this experiment was approved upon ethics review by the Department of Technology in Keio University (Keio University Faculty of Science and Technology Bioethics Committee Number 28-68).

**Table 6.1** Details of Experiment A and Experiment B

| | Experiment A: free conversation | Experiment B: conversation with an objective of problem-solving |
|---|---|---|
| Demographic of participants | Postgraduate students and adults in the workforce | Postgraduate students and adults in the workforce |
| Number of participants | Five pairs, total of ten participants | Six pairs, total of 12 participants |
| Venue | Keio University, Hiyoshi Campus | Keio University, Hiyoshi Campus |
| Duration | 27 min of free conversation between a pair in a room | No limits were set for answering questions, and the experiment was continued until they were all answered. Due to this reason, the duration of the experiment varied among pairs. The specific time duration for each pair is as mentioned in Table 6.2 |
| Method | Subjects were requested to start a conversation. Any special topic was not given; therefore, subjects can talk freely | In order to determine how much the position of two individuals in a conversation can affect the communication itself, one individual from a pair was asked to present the three questions listed in Table 6.3. The other individual from the pair was asked to answer these questions. These questions were prepared using the article [8] by Lile Jia et al. as reference. In order to prevent the conversation from cutting off due to the person answering the questions going into deep thought, the person asking the questions was requested to provide clues in order to lead their partner to the appropriate answers. This way, continuing communication was ensured |

## 6.4 Analysis

Below are the observations and analysis based on data collected from Experiments A and B.

### *6.4.1 Analysis of Experiment A*

Utilizing the time resolution of the Kansei Analyzer to record data every second, it was observed if there was any synchronization of Kansei values of two individuals

**Table 6.2** Time spent on preparations and solving the questions in Experiment B

| | Preparation (s) | Question 1 (s) | Question 2 (s) | Question 3 (s) |
|---|---|---|---|---|
| Pair 1 | 213 | 160 | 170 | 298 |
| Pair 2 | 405 | 253 | 235 | 283 |
| Pair 3 | 551 | 220 | 228 | 301 |
| Pair 4 | 311 | 164 | 345 | 76 |
| Pair 5 | 119 | 285 | 390 | 166 |
| Pair 6 | 323 | 200 | 375 | 106 |

**Table 6.3** Questions and example answers in Experiment B

| | Text read by the questioner | Example solution |
|---|---|---|
| Question 1 | A prisoner was attempting to escape from a tower. He found a rope in his cell that was half as long enough to permit him to reach the ground safely. He divided the rope in half, tied the two parts together, and escaped. How could he have done this? | He unraveled the rope lengthwise and tied the remaining strands together |
| Question 2 | A dealer in antique coins got an offer to buy a beautiful bronze coin. The coin had an emperor's head on one side and the date 544 B.C. stamped on the other. The dealer examined the coin, but instead of buying it, he called the police. Why? | In 544 B.C. Jesus had not been born, so a coin from that time would not be marked "B.C." |
| Question 3 | Show how you can make the triangle below [see Fig. 6.2] point downward by moving only three of the circles | |

within a pair. In Experiment A, the Pearson correlation coefficient during free conversations was calculated and the combination showing 5% significance was indicated by P (positive correlation) or N (negative correlation). In Table 6.4, subjects with odd numbers are labeled ODD and even numbered subjects EVEN. Nothing has been entered where there was less than 5% significance value. Throughout all the combinations, there was no correlation with two-thirds or more pairs with similar significance levels.

### *6.4.2 Analysis of Experiment B*

In Experiment B, there were two roles—the questioners and the respondent. It was verified whether there was a significant difference between these roles. Firstly, it was determined, both before and after the questions were asked, what sort of

**Table 6.4** Significant levels of correlation between the two subjects in free conversation

| | E[a]-Like | E-Interest | E-Concentration | E-Calmness | E-Stress |
|---|---|---|---|---|---|
| O[b]-Like | P[c] | NPP | N[d] | | P |
| O-Interest | | PPP | N | | PNN |
| O-Concentration | PN | NNN | PPP | P | PPN |
| O-Calmness | N | N | | | |
| O-Stress | NN | NNN | NP | | NP |

[a]"E" stands for even-numbered subjects
[b]"O" stands for odd-numbered subjects
[c]"P" means the positive correlation of significant value
[d]"N" means the negative correlation of significant value

**Table 6.5** Questioners' average values before and after the questions started in Experiment-B

| Subject ID# | *Q*1 | *Q*2 | *Q*3 | *Q*4 | *Q*5 | *Q*6 |
|---|---|---|---|---|---|---|
| Like (before) | 51.86 | 53.65 | 54.21 | 56.79 | 44.38 | 49.18 |
| Interest (before) | 33.42 | 33.71 | 44.53 | 17.64 | 35.72 | 24.69 |
| Concentration (before) | 32.18 | 36.31 | 36.87 | 34.81 | 36.26 | 36.78 |
| Calmness (before) | 27.00 | 29.06 | 27.26 | 27.23 | 30.67 | 31.48 |
| Stress (before) | 23.53 | 38.49 | 30.36 | 41.97 | 49.38 | 39.38 |
| Like (after) | 54.56 | 52.54 | 53.38 | 56.25 | 43.51 | 52.72 |
| Interest (after) | 49.33 | 38.42 | 46.33 | 30.43 | 38.15 | 48.59 |
| Concentration (after) | 23.45 | 41.82 | 35.58 | 37.94 | 38.72 | 34.62 |
| Calmness (after) | 25.78 | 30.12 | 28.30 | 28.81 | 29.41 | 29.01 |
| Stress (after) | 20.58 | 30.80 | 27.05 | 38.97 | 36.69 | 35.55 |

**Table 6.6** Result of t-test checking the difference of questioner values between before and after the questions started

| | *p*-value |
|---|---|
| Like | 0.589908836 |
| Interest | 0.035698662 |
| Concentration | 0.934982287 |
| Calmness | 0.770535604 |
| Stress | 0.017631137 |

changes occurred within the group of questioners and the group of respondents, respectively. Table 6.5 shows the average values for the questioners before and after the questions were asked. Using these values, changes in values before and after the questions are observed. This time, because we are comparing changes unique to each individual, a paired t-test was conducted on corresponding values. Table 6.6 shows the results. From this, the following observations can be made:

- Among the questioners group, the "interest" value is significantly higher after the questions had been asked.
- Among the questioners group, the "stress" value is significantly smaller after the questions had been asked.

**Table 6.7** Respondents' average values before and after the questions started in Experiment-B

| Subject ID# | *R*1 | *R*2 | *R*3 | *R*4 | *R*5 | *R*6 |
|---|---|---|---|---|---|---|
| Like (before) | 52.95 | 54.39 | 58.04 | 42.73 | 48.13 | 49.45 |
| Interest (before) | 31.32 | 16.31 | 43.49 | 25.12 | 41.13 | 30.95 |
| Concentration (before) | 51.77 | 60.78 | 33.49 | 30.10 | 36.38 | 45.39 |
| Calmness (before) | 29.11 | 30.65 | 29.48 | 28.35 | 28.07 | 27.32 |
| Stress (before) | 37.57 | 38.32 | 33.91 | 50.85 | 27.27 | 36.52 |
| Like (after) | 54.63 | 53.72 | 60.97 | 42.76 | 51.57 | 49.85 |
| Interest (after) | 36.61 | 28.46 | 50.26 | 34.32 | 46.77 | 39.74 |
| Concentration (after) | 55.36 | 70.11 | 35.25 | 38.37 | 44.19 | 42.33 |
| Calmness (after) | 29.07 | 31.57 | 28.79 | 27.90 | 28.42 | 26.50 |
| Stress (after) | 31.56 | 29.69 | 31.20 | 28.92 | 31.83 | 29.77 |

**Table 6.8** Result of t-test checking the difference of respondent values between before and after the questions started

| | *p*-value |
|---|---|
| Like | 0.112090285 |
| Interest | 0.000656876 |
| Concentration | 0.063989798 |
| Calmness | 0.680795888 |
| Stress | 0.109305498 |

- Among the questioners group, there was no significant difference in the "like," "concentration," and "calmness" values before and after the questions had been asked.

Table 6.7 is a list of the average values before and after the questions were asked, among the respondents group. Using these values as a control, changes in values before and after the questions were asked are observed. Because we are comparing changes for each individual, a paired t-test was carried out on corresponding values. Table 6.8 shows the results. From this, the below observations can be made:

- Among the respondents group, the "interest" value is significantly higher after the questions had been asked.
- Among the respondents group, there was no significant difference in the "like," "concentration," "calmness," and "stress" values before and after the questions had been asked.

Furthermore, for Experiment-B, Table 6.9 shows the Pearson correlation coefficient which was calculated for when the questions were being asked, and the combination showing 5% significance was indicated by P (positive correlation) or N (negative correlation). Nothing has been entered where there was less than 5% significance value. In Table 6.9, from the combinations with significant levels of correlation, we first looked at the "stress" values of the questioners and the

**Table 6.9** Significant levels of correlation between the questioners and respondents in Experiment B

| | Q[a]-Like | Q-Interest | Q-Concentration | Q-Calmness | Q-Stress |
|---|---|---|---|---|---|
| R[b]-Like (before) | P[c] | PP | PP | N[d] | |
| R-Interest (before) | PPN | PPP | N | N | P |
| R-Concentration (before) | PPP | PNN | NNP | | |
| R-Calmness (before) | | N | P | | |
| R-Stress (before) | N | PNP | PN | PN | PP |
| R-Like (after) | N | NP | NNNN | N | N |
| R-Interest (after) | | PNN | PN | N | NP |
| R-Concentration (after) | N | PNN | NPNPP | N | NP |
| R-Calmness (after) | | N | | P | |
| R-Stress (after) | NN | NNN | NPN | PP | PPPNP |

[a]"Q" stands for subjects in the questioner roles
[b]"R" stands for subjects in the respondent roles
[c]"P" means the positive correlation of significant value
[d]"N" means the negative correlation of significant value

respondents. Even in pairs where there were no indications of significant correlations before the questions were asked, there were four positive correlations in the "stress" values after the questions had been started. From this, we can extrapolate that from the act of asking or answering questions, synchronization of positive correlation of "stress" values was induced.

Moreover, there was a negative correlation between the "concentration" values of the questioners and "like" values of the respondents in all pairs (significance of more than 5% in four pairs out of five, as can be seen in Table 6.9. Figures 6.3 and 6.4 are a pair of an example showing this change. The positive correlation of a pair which was observed before the questions were started (Fig. 6.3) turned into a negative correlation after the questions were started (Fig. 6.4). There are no other correlations as such between any other values in Experiment-B. Just for the sake of confirmation, the opposite relationship, that is, the correlation between the "like" values of the questioners and the "concentration" value of the respondents was observed, but there was none. From this, we can verify that the role clarification of the questioners and the respondents, by the act of asking and answering questions, induced the synchronization of the negative correlation of concentration values of the questioners and the like values of respondents.

The traits mentioned above for each of the Experiments A and B could not be confirmed in the other experiment; that is, there was no synchronization of "stress" values in free conversations or unique changes in "concentration" and "like" values in free conversations, and so on.

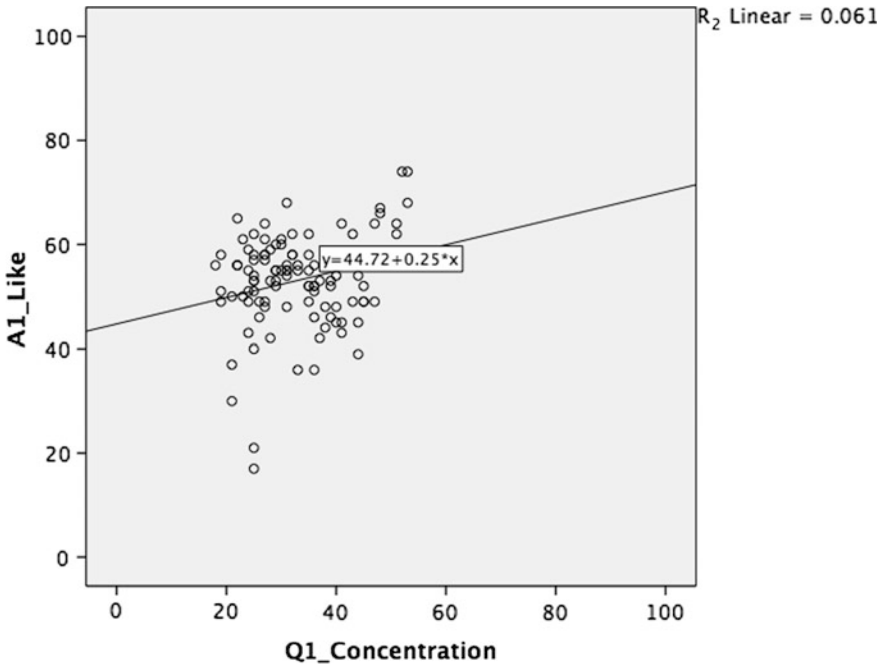


**Fig. 6.3** A questioner's "concentration" values and a respondent's "like" values (before the questions were started)

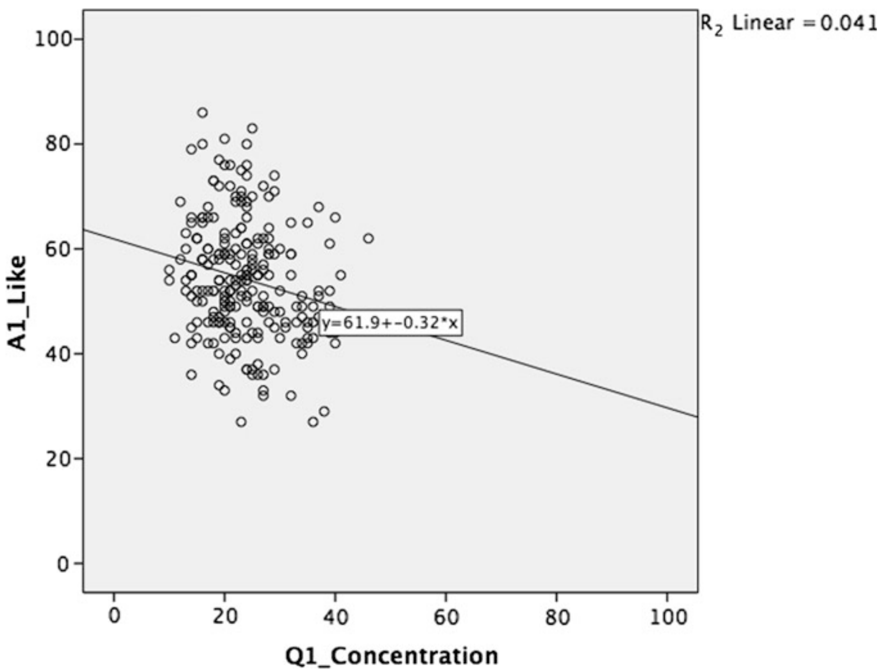


**Fig. 6.4** A questioner's "concentration" values and a respondent's "like" values (after the questions were started)

## 6.5 Discussion

As can be seen above, the Kansei Analyzer has been effective in analyzing communication. Its efficacy in elucidating human relationships that were built between participants was also proven through its contribution to comparing free and problem-solving conversations and finding unique traits in each of them. We can see that using the Kansei Analyzer to analyze communication can produce consistent results without creating a significant burden on the participants and, therefore, is a more appropriate method than other means that were used previously.

The below conclusion was drawn from experiments wherein the participants had known each other previously. Therefore, different results may be expected in a situation wherein they are meeting each other for the first time. In the future, we would like to experiment with participants who have not been acquainted with each other from before and compare with the results from this report.

Moreover, we believe that it could be interesting to also measure body movements with acceleration sensors while measuring EEG at the same time, or to study any relationship between the two, in the future as well.

Furthermore, the real-time nature of the Kansei Analyzer should be more emphasized. For example, this makes it possible to know from which point in time the relationship between people has changed. It will be easy to establish useful data for the construction of human relationships including the workplace and for smooth organization management, and it can be applied to various businesses.

## 6.6 Conclusion

In this report, we used Kansei Analyzer, which is a simplified EEG, as a means to measure internal human emotions during communication. Upon being given the tasks of asking and answering questions, the "interest" values increased significantly and "stress" values decreased significantly for the questioners after the questions had been asked, whereas only the "interest" values increased significantly for the respondents.

Moreover, we could also observe, through the time resolution of the Kansei Analyzer to measure in real time, that the synchronization index varied according to the contents of the conversations. More specifically, during problem-solving conversations, wherein specific roles were provided, positive correlation in "stress" values were synchronized. There was a synchronization of negative correlation in the questioners' "concentration" values and respondents' "like" values. There was no remarkable synchronization of the opposite, that is, the questioners' "like" values and respondents' "concentration" values.

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# Chapter 7
# Development of Ontology Toward Common Understanding of Human Sensibilities and Emotions

**Keiichi Muramatsu, Tatsunori Matsui and Keiichi Watanuki**

**Abstract** With the ongoing development of information and communications technology, it is apparent that computers will be indispensable partners in future human life. In terms of computer information processing, techniques for coordinating human sensitivity and emotional levels are attracting attention and stand in contrast to conventional knowledge information processing. In this chapter, we present an overview of content-oriented research considering knowledge itself and describe an approach to handling knowledge of human sensitivity and emotions using computers. First, we provide an overview of existing content-oriented studies in the field of artificial intelligence (AI). Second, we discuss problems regarding the handling of knowledge of human sensibilities and emotions. Then, we introduce an ontology pertaining to the concept of color emotion as an approach to understanding human sensibilities and emotions. Finally, we describe the applicability of such an ontology to human–computer interactions and for the understanding of human nature through the concept of analysis-by-synthesis.

**Keywords** Ontology · Knowledge sharing · Knowledge management
Human–computer interaction · Sensibilities · Emotions · Color emotion

## 7.1 Introduction

The development of information and communications technology (ICT) has had a remarkable effect on modern society. In addition to the widespread distribution of personal computers and broadband networks, mobile phones equipped with web

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browsers and, in particular, small computers known as "smart phones," are becoming widely used by individuals of all generations. These information infrastructures and terminal devices have changed the consumption and distribution of media, while providing widespread access to information via the Internet. For example, the means of transmitting information via mass communication has evolved from paper-based media such as newspapers or magazines, and broadcasting media such as television or radio, to Web-based media via the Internet.

The Web is a kind of electromagnetic medium. Therefore, it has multimedia characteristics that allow various types of information such as digitized characters, images, sounds, and moving pictures to be combined and processed in a unified manner. In a paper-based medium, the transmitted content and means of presentation are integrated; however, in electromagnetic media, these items are completely independent, with the means of presentation being dependent on the user interface of the access computer. For example, consumers have become familiar with multimodal interfaces, such as voice-based searching using voice input in addition to conventional keyboard input. Thus, consumers are provided with rich media consumption through "multimedization" and "multimodalization" of communication, with computer technology as the core.

In addition, computer performance levels have improved dramatically. As communication increasingly incorporates multimedia and multimodal technology, users must now decide how to consume the large amounts of information provided by these media. This is because the number of communication channels and the amount of information to be transmitted is increasing. Therefore, it is desirable to develop ICT in a manner commensurate with the natures of individuals, so as to take full account of the nature of each person receiving information. For example, it is conceivable that large amounts of information can be summarized and relevant information only can be presented to users. Further, for a given incidence of communication, not only text, but also voice and moving images can be conveyed, which increases the sense of presence. Hence, user emotions may be appropriately transmitted. Overall, to enhance ICT in the present age, it is necessary to understand the manner in which human beings manage media, and to understand the knowledge structure and emotions of humans. In other words, the knowledge that allows humans to behave intelligently and emotionally must be clarified. Development that can achieve better relationships between human beings and computers is expected to be realized through information processing of that knowledge.

Computers will be indispensable partners in future human life, as a result of the development of ICT. In the field of artificial intelligence (AI), research on the realization of intelligent behaviors similar to those of humans by computers has been conducted. Coupled with the rapid spread of the Internet, recent research on knowledge processing has led to the resolution of difficult problems through use of large data sets, known as "big data." As a result of the big data trend, the current emphasis in the field of knowledge processing is on mining for large amounts of data and similar techniques; however, research on methodology for managing the data itself is ongoing. In terms of computer information processing, techniques for coordinating human sensitivity and emotional levels known as "affective computing" are attracting attention; these techniques are in contrast to conventional knowledge information processing.

In this chapter, we present an overview of content-oriented research considering knowledge itself. Then, we discuss an approach to handling knowledge of human sensitivity and emotions by computers.

## 7.2 Content-Oriented Research

AI research can be roughly divided into two types of studies: formal studies oriented on logic (knowledge representation) and reasoning, and content-oriented studies typified by a knowledge base and ontology. However, in a knowledge-based expert system, it is very costly to convert expert knowledge into a knowledge representation and to construct and maintain the knowledge base. This is one reason why the success of expert systems is said to be limited. The problems afflicting content-oriented research have been summarized by Mizoguchi [16], as follows:

1. "Basic assumptions of a knowledge-based system are left implicit, which prohibits us from sharing and reusing knowledge.
2. There exists no common knowledge base on top of which we can build another knowledge base.
3. There is no sophisticated way to accumulate knowledge."

To overcome these problems, systematization of knowledge and concepts through an ontological approach has been conducted. In the context of AI, an ontology is defined as an "explicit specification of a conceptualization [8]." The knowledge base perspective takes an "ontology as a building block for constructing artificial systems. It is said to be the basic concept/vocabulary system (theory) to be used [18]." That is, an ontology is a common basis for knowledge descriptions that can be understood by both humans and computers. An ontology is generally divided into two sub-ontologies depending on the knowledge to be described. One sub-ontology is the domain ontology, which describes the knowledge of the target area, whereas the other is the task ontology that describes the knowledge of the processes [16]. Existing examples of domain ontologies include an ontology pertaining to disease in the medical field [29] and an ontology pertaining to teaching and learning theory in the field of education [10]. An example of a task ontology is the ontology of an oil refining plant reported by Mizoguchi et al. [20]. In these examples, the ontology provides specifications for modeling real problems by clarifying the conceptualization of the target world.

It is difficult to form logical expressions for items such as the attributes of physical objects that appeal to the human mind, which have not been examined on a long-term basis in research on conventional knowledge information processing. Affective computing or "Kansei information processing" is a research field that attempts to capture and control such information. The word Kansei is a Japanese concept that means mental functions including sensitivity, sensibility, emotion, and intuition. This research field is an interdisciplinary one incorporating both psychology and informatics that attempts to computerize human sensibility by borrowing methods to measure subjective responses previously developed in the field of psychology. It is expected that machine sensibility, that is, artificial Kansei, will be realized by an information processing system that solves problems or supports their resolution in situations where human sensibility is exerted, such as product design. When this artificial Kansei system performs some kind of problem-solving or support task, it is expected to employ a domain model contained within the system, which will model items in the target area either explicitly or implicitly. In order to clarify such a domain model, a methodology for domain analysis and modeling has been developed in the field of software engineering. Domain analysis contributes to organization and reuse of the knowledge of domains handled by the system. Further, domain models specialized for the target domain can be obtained by specializing general models.

The domain analysis and modeling approach is an attempt to systematize the reuse of knowledge in system development; however, a problem remains regarding the nature of the knowledge itself used to construct the system. That is, the domain model represents some item in the real world. When the analysis and modeling process is applied to individual target areas, an independent domain model can be obtained for each process. Therefore, it is difficult to develop a consistent foundation for the manner in which each domain model is obtained by specializing general models.

Thus, we must consider model sharing at the level of the concept that defines knowledge in the domain model of the target domain. The ontology, which is the conceptual basis of knowledge, can play a role in providing the specifications of such a domain model. One example of this approach is the construction of an engineering domain ontology for a domain model [11]. This domain ontology describes the concept of the spatial structure and temporal behavior that define the domain model of the physical world. For example, physical relationships and functional systems, such as the manner in which the components of an electric circuit and an electrical connection are connected, are spatial structures. The temporal behavior corresponds to the changes in the physical quantities of these components. Construction of such a conceptual basis may make it possible to describe and manage domain models related to problem-solving or support for engineering actions, such as design and fault diagnosis, in a unified manner.

## 7.3 Problems Regarding the Handling of Knowledge of Human Sensibilities and Emotions

A review of the history of mankind reveals human beings attempting to enrich their lives while modifying their environment. In this sense, as regards the development of media in information society, computers have come to be indispensable not only as a tool, but also as part of the environment. To further enhance human quality of life, it is considered necessary for a good relationship to be established between human beings and computers. That is, future development will establish a way for humans and computers to coexist. Here, the achievement of harmonious coexistence between humans and computers is expected to involve exploitation of the advantages of both human beings and computers, with their respective shortcomings being overcome. With regard to the human cognitive attitude toward media, as stated in the book *The Media Equation* [26], humans make specific types of contact with computers. Therefore, to establish a good relationship between humans and computers, ongoing technological development adapted to human characteristics is considered desirable.

Among the current efforts in AI research, possible directions for future technological development include (1) concrete emphasis of the content of knowledge itself in knowledge information processing, and (2) management of human emotions as Kansei information processing. The former aims to accumulate knowledge of human beings that can be handled by computers, with a conceptual basis common to humans and computers being constructed as a result. For example, if the basic technology related to conversion, summarization, and integration of media is realized by an ontology, the associated computer can be expected to communicate based on an "understanding" of human knowledge. The aim of the latter developmental direction is to computerize human intuitive mental work, which is not considered in the context of conventional knowledge information processing, and to handle this information using computers. Hence, it is thought that computers will be able to "understand" human sensibility or Kansei in communications. This will be the first step toward the coexistence of human beings and computers in society, i.e., the establishment of a better relationship between humans and computers on the basis of "understanding" by computers.

Here, the concept of "understanding" by a computer has two meanings. One is the apparent meaning, where a person situated before a computer seems to be "understood" by the computer. The second meaning is the case where computers "understand" humans exactly, in the manner in which humans understand other people. These two meanings correspond to the standpoints of weak and strong AI, respectively. To meet this goal, computers are not necessarily required to be equivalent to humans, as it is only necessary to aim for the first definition of "understanding." However, even if we do not adopt a strong AI position, the manner in which humans can understand their own sensibilities or Kansei must be clarified to facilitate the future development of technology in accordance with the nature of human beings. At present, insufficient relevant knowledge has been acquired in the fields of cognitive science and psychology to elucidate this aspect of human beings. Therefore, the current problem concerns realization of "understanding" of human knowledge and sensibility by a computer from a weak AI standpoint.

Both knowledge information processing and Kansei information processing have the same purpose in the same engineering field, in the sense of attempting to realize human minds for computers. In addition, cognitive science and psychology (a component of cognitive science), which are approaching engineering, are fields of science attempting to elucidate the human mind. In the broad sense of AI research that encompasses the fields of engineering and science and aims to understand essence through making, so-called analysis-by-synthesis is used as a thought process to elucidate human intelligence and Kansei. The concept of analysis-by-synthesis is derived from the cyclic model by Neisser [23] that explains perception through bottom-up and top-down processes and is regarded as a method of determining parameters by sequential approximation in visual or auditory modeling. This concept is applicable to both knowledge information processing and Kansei information processing. It is useful for elucidating and realizing the human mind, including intelligence and Kansei. Note that agreement on approaches to understanding the workings of the mind known as Kansei is difficult to achieve, even in the fields of informatics and psychology, and the obtained findings are not systematically positioned. Realization of artificial Kansei through Kansei information processing and, also, elucidation of human Kansei in psychology must be promoted mutually. By unifying the knowledge associated with both of these areas in a consistent manner, a desirable research approach based on the concept of analysis-by-synthesis can be established.

## 7.4 Understanding Sensibilities and Emotions Through Content-Oriented Approach

In order for computers to "understand" human beings, a research approach to elucidate human Kansei by creating artificial Kansei on a computer must be established. If we apply the concept of analysis-by-synthesis to AI research in the fields of science related to Kansei information processing (mainly psychology) first, we will begin to construct hypothetical artificial Kansei based on previously obtained knowledge. It is thought that knowledge of the intrinsic properties of human Kansei can be obtained by comparing artificial Kansei with actual human Kansei.

In order to compare artificial and human Kansei, it is necessary to consistently describe knowledge acquired in the engineering and scientific fields related to Kansei information processing, so as to establish a foundation. That is, if the modules and parameters of artificial Kansei and the knowledge constituting the artificial Kansei itself are described in a unified manner, the degree to which the artificial Kansei can reproduce the functions of human Kansei will become clear. Therefore, the proposal of a content-oriented approach to systematically unifying the knowledge handled in the related fields has been set as a research purpose, in order to understand human Kansei and to compose artificial Kansei. The knowledge used to construct artificial Kansei can be regarded as a domain model that is explicitly or implicitly assumed in engineering and scientific fields. The domain model in Kansei information processing handles the mental world regarded as the interior of the human mind in addition to the physical world, similar to the engineering domain ontology [11] described above.

In order to uniformly describe the domain model in the fields of engineering and science related to Kansei information processing, it is necessary to construct a conceptual basis for cross-cutting knowledge utilizing informatics and psychology. One of the problems here is that the methods used to acquire sensibility in those research fields differ. These differences seem to originate from different conceptualizations of the human mind; thus, it is necessary to set a viewpoint that allows researchers to obtain a common understanding. It is difficult to cover all specific research subjects related to the field of informatics and psychology in order to establish a reasonable approach to handling the mental world by analyzing the target area. Therefore, in this chapter, we examine the knowledge (domain model) and concept (ontology) that form the specification by limiting the objects described as knowledge. Although the problem targeted here is to develop methods for computers to understand humans, we do not necessarily aim to clarify knowledge and concepts for all research subjects in informatics and psychology. By limiting the specific research subjects, we aim to show that the content-oriented approach is useful for human understanding.

In this chapter, we focus on the concept of color emotion, which is a kind of esthetic sensibility to color, and set it as a target area in order to grasp the behavior of human Kansei. In addition to esthetics, the concept of esthetic sensibility has also been adopted as a subject of research in the field of psychology, and it is felt that the workings of the human mind can be determined with a broad perspective in this regard. In addition, vision research is more widespread than that for the other senses, especially with regard to color perception and cognition, and understanding of these behaviors is progressing through various models of the optic nerve and brain region. In addition to the perception and cognition of color appearance, considerable research on feelings and emotions has been reported, in which the impressions stimulated by colors have been examined. As the results of experiments on color emotion are often represented by statistical models and are applied to AI systems based on those models, color emotion is considered to be a suitable topic for this discussion.

Color emotions are referred to as “emotional responses to color stimulus” and are of considerable interest in color science. Color emotions include emotional evaluations such as comfort and discomfort as well as impressions of the appearance of color. Therefore, they can be regarded as esthetic sensibilities when the evaluation target is limited to color. Color emotions are determined through subjective measurement using rating scales and questionnaire items, and the relationships with lightness, saturation, and hue have been well discussed [6, 24]. In addition, a design support system that predicts color emotions based on such colorimetric quantities has been developed [25].

The knowledge of color science required to construct artificial Kansei is often stated to be data on subjective evaluations and colorimetry, along with a statistical model of the relationship between them. These descriptions of data and models are used for understanding and support of color emotions by computers. Therefore, in order to construct an artificial Kansei of color emotions, a conceptual basis must be constructed by conceptualizing the concept of data description and model representation; this is a domain model. However, it is necessary to collect and organize knowledge (instances) for concept systematization, as there are many unknown points on the dimensions that capture the structures of color emotions.

Studies of color emotions roughly divide the results into two dimensions; such as "comfortable, uncomfortable," and "good, bad," belong to the evaluative dimension, and such as "warm, cold," "bright, dark," and "soft, hard" belong to the descriptive dimension [6]. With respect to the descriptive dimension of a single color, three factors corresponding to $L^*$, $C^*$, and $h$ in the CIELCh color space have been extracted from a factor analysis of ratings obtained from subjects in seven different countries and regions [7]. However, with regard to the evaluation dimension of color emotions, large cultural and individual differences exist; thus, the relationship to descriptive dimensions has not been clarified. In addition, the dimension concerning the emotional state has been investigated [27, 28] as an alternative approach to that used for the previous evaluation and descriptive dimensions. Few studies on the dimensions of emotional states treated as one of the color emotions have been reported, however, and the relationship between the emotional state dimension and the color attribute has not been clarified sufficiently. Therefore, in order to organize domain models in color science, it is necessary to distinguish descriptive and evaluation dimensions of color emotions, along with emotional state dimensions, and to clarify the respective data descriptions and model representations.

## 7.5 Issues Affecting Ontology Construction

Research trends on ontology concerning feelings and emotions include investigations of tactile senses to provide a common vocabulary for system development, along with construction of a conceptual model for the process through which emotions manifest [14, 22]. However, these ontologies are exhaustive classifications of individual concepts that are basically expressed in a formal manner on a computer. That is, a conceptual model that enables description of the content that human beings feel in a specific context has not been achieved. As regards ontologies pertaining to aspects other than sensitivity and emotion, they mainly aid the conceptualization of items that exist prior to human perception, and the results experienced by humans, such as psychological reactions in the form of feelings and emotions, have not been examined. Previous related studies [14, 22] have explored a conceptual model only of the physiological response through which sensations and emotions manifest. Therefore, a new attempt to model the structure of psychological reactions expressing the content of the human mind, which should be in the form of an ontology, is necessary.

In this discussion, data descriptions such as the rating value for a subjective evaluation and a colorimetric value are regarded as knowledge (instance model), and the concept of the mental attitude on which the knowledge is premised corresponds to the ontology. By constructing this ontology, it is possible to clarify the specifications that can be used to represent the mental world (which cannot be directly observed) as a domain model. In color science, data on rating scales and colorimetric values are measured or quantified through a predetermined procedure. Therefore, when constructing an ontology, the task is to describe the nature of items related to color emotions as data. In other words, regarding the data description of a rating value, the point of discussion is how to express and treat the mental content arising in the case of an esthetic experience as a numerical value. The colorimetric values are called psychophysical quantities which are defined by color matching functions and the amount of radiation, whereas the rating values are called psychological quantities. Therefore, regarding the data description of colorimetric values, the problem to be overcome is their definition in terms of both psychological and psychophysical quantities.

## 7.6 Example of Ontology Construction

This section presents an example of an ontology that was constructed by the authors in a previous study [21]. This ontology pertains to emotional responses to color stimuli, which are referred to as color emotions as explained above. To specify the concepts related to color emotions, this ontology defines attributes of awareness on the basis of a top-level ontology. This is essential for the handling of knowledge of human sensitivity and emotions by computers.

### *7.6.1 Method of Ontological Development*

Ontological engineering is one of the methodologies that supports the systematic description of knowledge. From the knowledge-based viewpoint, an "ontology is defined as a theory (system) of concepts/vocabulary used as building blocks of an information processing system" [25]. In the Hozo ontology development environment [12], each node represents a basic concept and possesses slots that represent part-of or attribute-of relations (Fig. 7.1). Hozo supports the description of role concepts, which represent a role depending on the content of each basic concept. For example, a teacher role is played by a human in a school context only, and he does not play that role outside of school. In other words, every slot has a role under the basic concept implying a context. In the context, the class of instances that can play roles is defined by a class constraint and is called a role holder [13]. In this way, the role concepts permit distinction between concepts under different contexts. Inherited role holders and class constraints imported from other ontologies are represented as shown in Fig. 7.1.

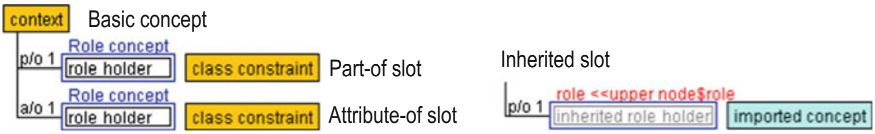


**Fig. 7.1** Legends of node and slots in Hozo (p/o part-of relation; a/o attribute-of relation) (Reproduced from Ref. [21])

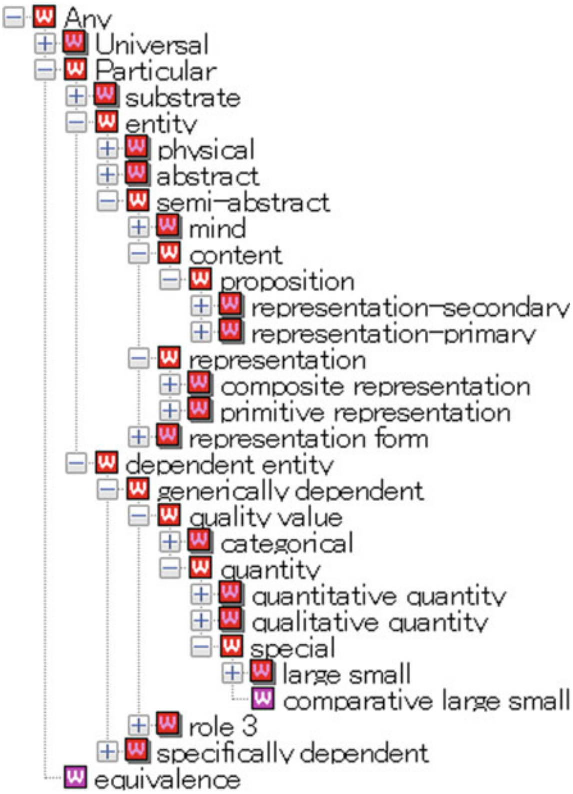


**Fig. 7.2** Overview of YAMATO framework (Reproduced from Ref. [21])

A top-level ontology known as "Yet Another More Advanced Top-level Ontology" (YAMATO) has been constructed on the basis of the role concept theory [19]. The top hierarchy of the YAMATO is shown in Fig. 7.2. In the YAMATO framework, the aspects of an entity are classified into three classes: physical, abstract, and semi-abstract. While instances of the physical class require 3D space and time to exist, instances of the abstract class require neither. Instances of the semi-abstract class require only time to exist, and this class contains mind, representation, content, and the representation form. That is, representations such as novels, poems, paintings, music, and symbols are distinguished from their proposition and the actual form of representation [17]. The representation class (Fig. 7.2) is further divided into primitive and composite representation, and a part-of slot is used for these divisions to indicate the component role played by a given representation. Further, the representation has part-of slots that indicate the content role played by the proposition and the form role played by the representation form. The proposition is also divided into two subclasses: representation-primary and representation-secondary. Both of these proposition classes necessarily depend on the representations that represent them. However, instances of the representation-secondary class, such as facts, data, and thoughts, indicate original content before their representation. For example, a fact exists as an event before the human recognition that expresses that event as a representation. In this sense, human recognitions including sensations and perceptions belong to the representation-secondary class.

The main features of YAMATO are definitions of qualities and quantities, representations of them, and descriptions of interrelationships among them in other top-level ontologies. Attributes of entities are represented as qualities that take quality values. Quality values are divided into the categorical and quantity classes which contain qualitative and quantitative quantities, respectively. Further, quality is divided into properties and generic qualities. A property is an abstraction of a generic quality taking a quality value, while a generic quality is further subdivided into intrinsic and accidental generic qualities. A basic generic quality, which contains quantitative and qualitative generic qualities, is a subclass of the intrinsic generic quality. For example, the quality of a color is defined as a subclass of the quantitative generic quality and takes a frequency quantity as the quality value, which is defined under the quantitative quantity. On the other hand, the name of a color, e.g., red or blue, is defined as a subclass of the categorical class. In YAMATO, representations of qualities and quantities are defined as transformations of a real quality into a representation through an action for measurement. The measurement has a part of slot that indicates the resultant role played by the primitive representation. The quality measurement is defined as a role holder corresponding to a proposition in a content role subslot of the result role slot. Data obtained through empirical measurements that represent measured values are necessarily approximations, and qualities (values) that represent true values are independent of any measurements. Therefore, representations of quality (value) itself must be clearly distinct from representations of measured qualities (values) obtained through empirical measurements [15]. For this reason, YAMATO provides a concept of data as a proposition under the representation-secondary class.

## *7.6.2 Qualities and Quantities Related to Color Emotion*

### 7.6.2.1 States and Actions Related to Awareness

According to Barušs [1], consciousness is defined as a fully subjective awareness characterized by intentionality, along with the explicit knowledge of one's situation,

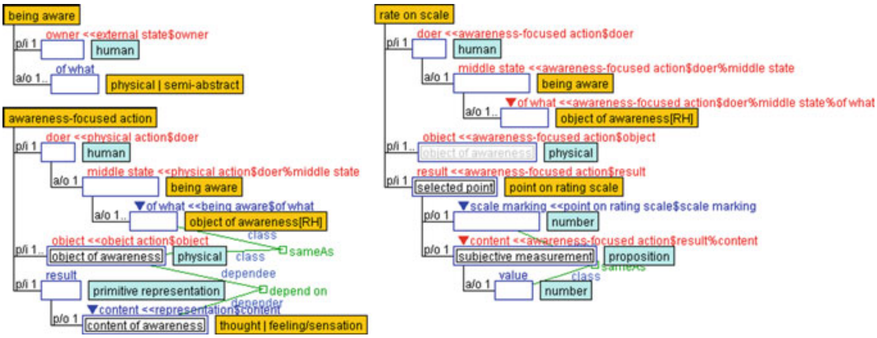


**Fig. 7.3** State of being aware and awareness-focused action (Reproduced from Ref. [21])

mental states, or actions evidenced behaviorally. This definition indicates two types of consciousness; subjective and behavioral. Thoughts, feelings, and sensations that manifest in persons are classed as subjective awareness, and the awareness expressed through one's behaviors is regarded as behavioral awareness [2]. That is, in objective research considering awareness, behavioral consciousness is defined as operationalization of the subjective consciousness.

In YAMATO, these two types of awareness can be specified using the external state and actor state action. Figure 7.3 shows the state of being aware and awareness-focused action. The state of being aware is defined as a subclass of the "external state" in YAMATO. Objects of awareness are represented by of-what role holders, corresponding to a physical or semi-abstract class. Further, the action is defined as a subclass of the "actor state action" in YAMATO and is composed of doer, object, and result slots. The doer role is played by a human and its "middle state" is specialized as the "being aware" state. The of-what role is played by the "object of awareness," which is a role holder in the object slot, and they are linked by a "same as" link. The doer's awareness can be observed only when it is explicitly expressed. Therefore, the "content of awareness" is defined as the role holder of a content role under the result slot and is linked to the object of consciousness by a "depend-on" link.

### 7.6.2.2 Attributes of Awareness

The definitions of the object of awareness and content of awareness allow attributes recognized by humans to be distinguished from YAMATO's qualities and quality values. Color attributes such as lightness, chroma, and hue are regarded as psychological quantities that only exist in human awareness. Figure 7.4 shows qualities and quality values for awareness. Each is defined for a subclass of qualities and quality values in YAMATO. The class constraint of the "on what" slot inherited from each parent is an object of awareness. One of the referring-to role in the "quality on awareness" is played by the quantitative perceptual quality value and

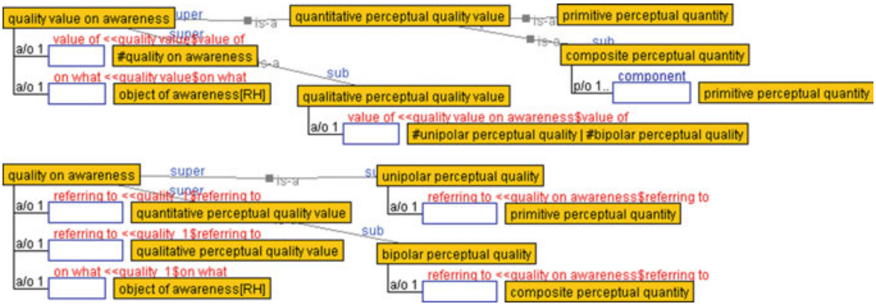


**Fig. 7.4** Quality value and qualities on awareness (Reproduced from Ref. [21])

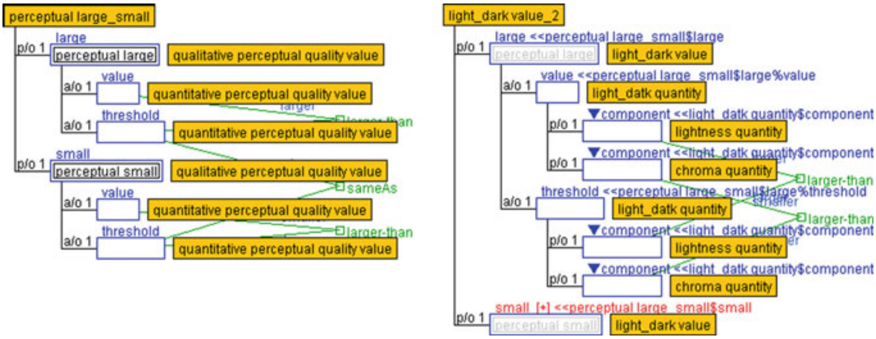


**Fig. 7.5** Perceptual large and small framework (Reproduced from Ref. [21])

the other is played by the qualitative perceptual quality value. Role players are defined as subclasses of the “quality value on awareness.” The quantitative perceptual quality value is divided into primitive and composite perceptual quantities, which are conceptualizations of psychological quantities. As regards the color attributes, lightness, chroma, and hue are regarded as primitive perceptual quantities and constitute composite perceptual quantities.

The quantitative perceptual qualities are divided into unipolar and bipolar perceptual qualities, which take primitive and composite perceptual quantities, respectively, as quality values. For example, color appearance judgments based on human perception, such as light-dark, soft-hard, and warm-cool, can be defined as bipolar perceptual qualities and take composite perceptual quantities, such as a light-dark, soft-hard, or warm-cool quantity. With regard to the quantitative perceptual quality values, they also take qualitative perceptual quality values such as light-dark, soft-hard, or warm-cool values. The relationships between these quantitative and qualitative perceptual quality values can be specified under a perceptual large and small framework, which is regarded as homologous with the large and small framework in YAMATO (Fig. 7.5). In this context, perceptual large and perceptual small are represented by qualitative perceptual quality values, and value and threshold are represented by a quantitative perceptual quality values. Consequently, values qualitatively indicating larger and smaller items are specified by introducing thresholds that are assigned quantitative values.

## 7.7 Applicability of Ontology

The result of this ontology construction can be applied to the conceptual base for experiments to observe interactions between humans and computers, with the aim of confirming human empathy and synchronous reactions for computers. The confirmation of sympathy and entrainment reactions in interaction experiments would indicate that computers and humans share very close concepts of the given content as a result of the employed ontology. Hence, human–computer interaction could be realized on a deep level, through knowledge processing implemented at a content level deeper than the conventional formal level. Thus, the realization of artificial Kansei in computers based on the conceptual basis of psychological reactions is positioned to be one of the new methods of analysis-by-synthesis in AI research.

To realize a computer that performs deep-level interaction with humans in the field of human–robot interaction (HRI), as part of the symbolic ground problem [9], the problem of associating data from sensors and symbolic concepts (the anchoring problem) must be considered [3]. This problem refers to the correspondence between the object recognized by the robot and its knowledge representation. The information processing system that determines the robot behavior can function using a layer that recognizes the object based on data from a sensor, and a separate layer that performs reasoning using knowledge representation of the object. The function performed by the layer for sensor-based recognition is equivalent to recognition of the object and its properties from the image feature degree using an algorithm such as machine learning. On the other hand, in the reasoning layer, the recognized object is interpreted using knowledge representation based on ontology. To solve the problem of association between these layers, a layer simultaneously describing the concept and properties of the recognized object has been proposed [5]. For example, when a robot recognizes a mug from an image, the properties of the object (such as its color and shape) are estimated from the image feature quantity. Then, the estimated properties are described together with knowledge representations pertaining to colors and shapes based on the ontology and are managed by time-based identifiers. That is, in this layer, the recognized properties are associated with the instances of the concept described by the ontology, and the results recognized by the robot are systematically managed. Therefore, this behavior can be perceived as management of the “content of consciousness” of the robot.

In a study associating robot sensor data with knowledge representation of a CYC ontology [4], the identity of the object and its position and color features were appropriately exchanged in a dialogue between a user and robot. For example, in addition to knowledge of recognition results indicating that pink flowers are placed in the kitchen, the common sense knowledge that a flower is a living thing was shared by the user with the robot. Along with the concept of common sense knowledge organized by CYC, when the robot made a sensory utterance as a communication strategy, it is possible that the human perception of the object's texture was associated with the robot's recognition. As the ontology introduced in this chapter defines the concept of psychological attributes that human beings feel in response to objects, it is thought that this ontology contributes to the realization of deep interaction between humans and computers through association of robot recognition and psychological attributes.

## 7.8 Summary and Future Tasks

In a conventional ontology, color emotions and colorimetric values cannot be properly described because there is no concept of psychological attributes. On the other hand, using the ontology described in this chapter, it is possible to associate these data with knowledge representation. In that sense, the ontology description presented above seems to have high novelty and usefulness.

Although the ontology description introduced in this chapter makes a significant contribution to correspondence between data and knowledge representation, there is no possibility of contributing to reasoning using knowledge representation. In future work, a conceptual structure defined by an ontology for reasoning using knowledge representation will be used. At present, the target world of the ontology is restricted to knowledge expression based on emotional concepts and statistical models for a single color only. Therefore, expansion of the ontology concerning color emotion to multiple color combinations is another task for future research. Research on relationships between multicolor coloration and color emotions is ongoing in color science. However, if we can describe those relationships as ontologies in future research, it may become possible to infer a color desired by a user from the conceptual relation. This technology is expected to contribute greatly to design interaction on a deep level with humans, with the design support system obtaining coloration from the direction opposite to the genetic algorithm.

Finally, we have described the tasks pertaining to further understanding of human Kansei, including impressions and emotions, based on the idea of analysis-by-synthesis. The attribute/attribute value for consciousness defined in the ontology was conceptualized with the same degree of abstraction as the attribute/attribute value of an object defined in YAMATO. Therefore, the ontological descriptions do not depend on a specific research field. In other words, the ontological description for an attribute/attribute value for consciousness introduced in this chapter has versatile applicability in research fields in which emotional responses to color and similar psychometric methods are employed. Therefore, this ontology is regarded as a valuable guideline for sharing concepts on the structure of the human mind.

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# Chapter 8
# Feel of Fishing Reel

**Tetsuo Inoue and Syuhei Kurokawa**

**Abstract** What kind of image will you have in mind when you hear about a fishing reel? The fishing reel is a simple device that releases and winds up a fishing line. In a world of hobbies, the demand for designability and functionality is enhanced when it comes to luxury goods. A representative example of functionality is the feeling experienced during rotation of the reel (i.e., feel of a fishing reel). The feeling is a vibration, and it occurs owing to gear-pair engagement when the handle of the reel rotates. The best professional anglers have said that they can feel if it is water turbidity or the behavior of a fish from the change in the feel of the fishing reel. To satisfy their demand, we must control the accuracy of the gear to the sub-micrometer level. For this purpose, the shape of the tooth flank of the gear is precisely designed by three-dimensional computer-aided design (3D-CAD). However, anglers' demands increase each year. To respond to these demands, in addition to improving the tooth flank accuracy, we need to research the feel of the fishing reel. Initially, we must think about what is the feel of a fishing reel. We contributed to the research of the relationship between the vibration and the tactile sensitivity of the human finger. As a result, we elucidated that tactile sensation has a high correlation with the vibration of mesh frequency that occurs owing to gear-pair engagement. Using this phenomenon, we succeeded in developing a new feature called "micro-module gear ™." This function improves the feel of the fishing reel by adapting a small gear module. This is a technology born from an entirely new approach to the optimization of the mesh frequency. However, research on gear and sensitivity is underdeveloped. In this paper, we report some state-of-the-art studies in this underdeveloped field that improved the feel of fishing reel.

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## 8.1 Introduction

### *8.1.1 Feel of the Fishing Reel*

What will you think when you hear about the feel of a fishing reel? The function of the reel is winding up a fish, and we can think about an ideal winding up being light, comfortable, and quiet. However, most anglers are not conscious of the feel of the fishing reel when they wind up a fish. This paper discusses a function performed before winding up a fish rather than during winding up a fish—that is, the function of the reel in attracting fish by the motion of the fishing lure or bite. An angler performs various actions during fishing, for example, scooping a rod or changing the rotational speed of the reel handle. By these actions, they control the lure or the bite skillfully and the fish is attracted and caught. When this happens, the angler, concentrating on the reel or the rod, feels a fluctuation in the vibration of the lure or bite, which is transmitted via the fishing line. In order to accurately transmit underwater information to the angler, there should be no vibration when the reel rotates. It is said that professional anglers can feel the amount of mud or plankton in the water as well as the fluctuation of a fish when it approaches the lure. Therefore, they demand a reel that transmits information for winding up a fish accurately and without noise. However, the gear vibration cannot be suppressed completely because the gear and the handle are directly assembled. Consequently, anglers feel an uncomfortable gear vibration on their fingertips. Namely, when the gear vibration is large, the reel value deteriorates in the marketplace. When the gear vibration is small, they can enjoy fishing and get good fishing results. The feel of the fishing reel is the most important factor for good fishing results, and the demand for better feel increases each year. Generally, it is said that a good fishing reel feels like silk as we do not feel that two metals have come in contact. However, there is a paradox here; is no vibration or the silky vibration the best? For example, in the case of sound, silence (no sound) is better than noise, although nobody says that silence is the ultimate sound. Music is a combination of various sounds that makes people's mind comfortable. Even if the volume is high, nobody feels it is uncomfortable. There is silence beyond noise, and there is music beyond silence. In the case of vibration, is it possible to consider that there is no vibration beyond noise or if there is "vibration music" beyond no vibration?

### *8.1.2 Background*

There are mainly two types of fishing reels. The first is the bait casting reel in which the handle and the spool axis are parallel to each other. The spool is the winding part of the reel. The second is the spinning reel in which the handle axis and the spool axis are perpendicular (Fig. 8.1). A feature of the spinning reel is that it is trouble-free when an angler throws a gadget for fishing because the spool does not

**Fig. 8.1** Spinning reel

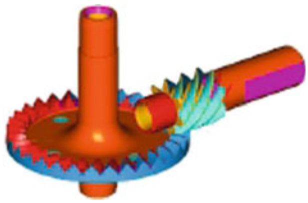


**Fig. 8.2** Face gear system

rotate at the time. Thus, the line does not get entangled with the spool. Currently almost all spinning reels utilize a face gear system (Fig. 8.2). In this study, a gear pair, comprising a small cylindrical gear and a large face gear, is defined as a face gear pair. In a gear pair involving face gears, the smaller gear is defined as the pinion and the larger one as the face gear. The face gear is easy to be formed and offers a good feel in handling the fishing reel. In this research, a spinning reel that employs the face gear system is the subject of study. The feel of the fishing reel is the result of the vibration that occurs from the gear system. The vibration is transmitted to the fingertips via the handle. In order to reduce the vibration, it is required to improve the accuracy of the reel body that keeps the gear system and the accuracy of the tooth flank of the gear pairs. In particular, the accuracy of the tooth flank is important; however, in a prior study [1], the authors revealed that the accuracy required is in the micrometer or sub-micrometer level. It is necessary to introduce a high-accuracy machine tool to realize this accuracy. Obtaining a good feel in the fishing reel results in an increase in the production cost.

### 8.1.3 Objective

The magnitude of the vibration that occurs from the gear pair is very small even in current manufacturing levels. Therefore, the feel of the fishing reel is assessed by expert skilled inspectors. However, the assessment is a sensory human evaluation;

therefore, it depends on the environment and physical condition of the inspectors. Such an evaluation is vague and inefficient; moreover, the feel of a fishing reel is not a quantitative parameter. In this paper, we report on a developed vibration measuring system which can measure the slightest vibration that occurs from the gear pair. The measurement results are analyzed, and the feel of the fishing reel is quantified. Consequently, a model that enables a quantitative assessment is constructed. In order to improve the feel of the fishing reel, it is required to elucidate the mechanism of what human feel is assessed as positive or negative. There have been many reports on the tactile sensation of human fingers [2, 3]. A paper reported on the velvet hand illusion [4]. Humans feel the vibrations by their fingertips; therefore, we might assume that their evaluation of the feel of a fishing reel is unrelated to the magnitude of the vibration. In the case of sound, it is well known that humans recognize different sounds by the variation in frequency even if the sound pressure level is the same [5]. In the case of the fishing reel, humans feel the vibration instead of the sound. Nonetheless, it is a human feeling and it can be assumed that there is a nonlinear relationship between amplitude and frequency similarly to the sound. In this paper, we report on a developed vibration simulator. The system can output various vibrations. Consequently, the relationship between the vibration felt by the fingertips and the tactile sensation is investigated. In the case of acoustic sensitivity, there are reports on the relationship between acoustic sensitivity of a human and sound [6–8] as well as the relationship between gear noise and sound pressure levels [9]. The sound was classified into four types, i.e., loudness, sharpness, roughness, and fluctuation strength. However, no report is available on the relationship between the tactile sensitivity of a human finger and the vibration generated by a gear pair. In this paper, we report the research results of classified patterns of the gear vibration. Consequently, the relationship between the vibration felt by the fingertip and the tactile sensation is elucidated.

### *8.1.4 Structure of This Paper*

This paper consists of seven sections including introductions and conclusions.

The first section is the introduction and describes the background and objective of this research.

The second section reports the findings on the quantification of the feel of a fishing reel based on the measurements of the face gear pair. Twelve face gear pairs which were manufactured in an author's prior study [10] are ranked by sensory human judgment using reel products. Those samples are accurately measured engagements of gear pair. Feels of fishing reels are estimated based on the ranking and measurement results by the Mahalanobis-Taguchi system (MT system) of robust engineering [11, 12]. Robust engineering is also known as Taguchi method.

The third section reports the results of the quantification of the feel of a fishing reel based on the vibrations measured on the reel handle. Five sample reels were prepared and ranked by sensory human judgment. The handle vibration of those sample reels was measured using a bone-conduction speaker (BCS) which uses a piezoelectric-type sensor. The slightest vibration is measured and converted to sound data. We investigated whether this system can distinguish slight vibration differences in high sensitivity.

The fourth section reports the relationship between the vibration felt by the fingertips and the tactile sensation. A vibration-generating machine (vibration simulator) was developed in order to simulate the vibrations instead of using actual reel products. We tried to elucidate the relationship between amplitude and frequency based on the sine wave vibration of the simulator.

The fifth section reports the investigation of waveform components of vibrations based on commercial reel products. The vibration waveform was classified into various types of fluctuation components based on sine wave. We tried to elucidate the relationship between fluctuation components and the tactile sensation using the vibration simulator.

The sixth section reports the results of a tooth flank modification of a face gear aimed to improve the feel of the fishing reel. Virtual high mesh frequencies were generated by the addition of grooves on the face gear tooth flank. We tried to develop a tooth flank that gives an illusion of the feel of a real fishing reel which was improved using this phenomenon.

Finally, the seventh section gives a comprehensive summary of this research and proposes future research in the field.

## 8.2 Quantification of Feel of Fishing Reel by Transmission Error Measurement of Face Gear Pair

### *8.2.1 Introduction*

In a previous study published by the authors [10], tooth flank modification of a face gear was optimized by the robust design method of robust engineering. Twelve samples were assessed and ranked by sensory human judgment by 21 evaluators. In mass production, the feel of the fishing reel is conventionally evaluated by expert inspectors. However, such evaluation is conducted based on sensory human judgment; therefore, it is vague and inefficient. In the robust design method, as many as 21 evaluators were required to assess the feel of fishing reels. This eliminates the vagueness as much as possible. In order to improve the feel of a fishing reel, its feel should be measured quantitatively and with high accuracy. In this section, a conversion of the feel of fishing reels into numerical values is attempted. The face gear pairs were engaged, and their transmission error (TE) was measured. The feel of fishing reel is forecasted using the obtained TE waveforms and ranking points. The MT method [12] was used as the calculation method.

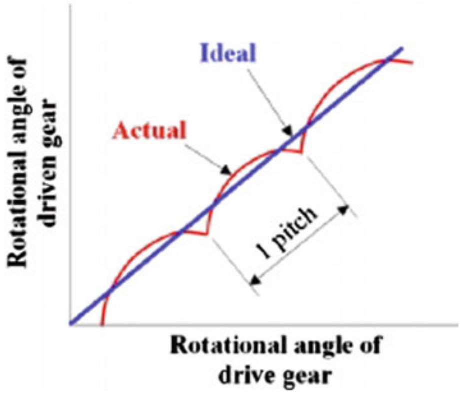



**Fig. 8.3** Ideal function of face gear pair

## *8.2.2 Ideal Function of Face Gear Pair*

In order to measure the feel of the fishing reel with high accuracy, an ideal function of the face gear pair was considered. Figure 8.3 shows the ideal function considered in this study. The *x*-axis represents the rotational angle of the drive gear, and the *y*-axis represents the rotational angle of the driven gear. The ideal function is to accurately transmit the rotational angle of the drive gear to the driven gear. Ideally, the relationship between the input and the output will be linear. However, in reality, the gear pair has manufacturing errors; therefore, the relationship will be nonlinear. TE measurement using a rotary encoder can provide the relationship between the input and the output of a gear pair with high accuracy. Therefore, we considered that the TE is the ideal function of the face gear pair. Figure 8.4 depicts a situation of measuring the TE of a face gear pair.

## *8.2.3 Definition of Best Estimate and Feature Quantities*

Accurate forecasting of the feel of a fishing reel requires that true values must be set strictly. In addition, many featured quantities related to the true value are required.

**Fig. 8.4** TE measurement

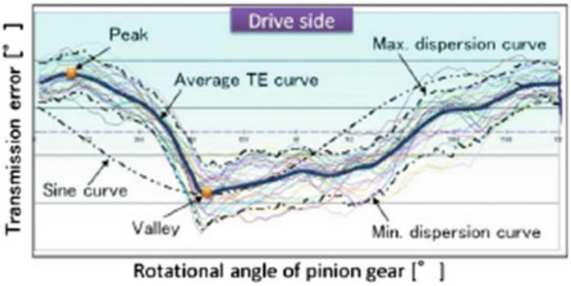



**Fig. 8.5** Converged TE waveform

In this study, the true value was referred to as the best estimate and the featured quantities were referred to as items. The twelve face gear samples were utilized for forecasting the feel of the fishing reel. These samples were measured by a TE measuring machine (TMM). The TMM used a 1,296,000 PPR rotary encoder in the driving and driven sides. The measured TE waveform for one rotation of the face gear was divided by the number of the face gear teeth. These divided waveforms were merged into one graph.

Figure 8.5 shows an example of the converged TE waveform. The $x$-axis represents the rotational angle of the pinion, and the $y$-axis represents the TE. Three types of items were extracted from this graph. The first item is called the "amplitude item" which is the P-V value of the average TE waveform and represents the magnitude of vibration. The second item is called the "distortion item" which is the difference between the average TE waveform and the sine waveform and represents the smoothness of vibration. The third item is called the "dispersive item" which is the area between the maximum and the minimum dispersion waveforms and represents the stability of vibration.

Figure 8.6 shows the relationship between the sample numbers and the ranking points. The $x$-axis represents the sample numbers, and the $y$-axis represents the ranking points. The best estimate was defined as the average of the rankings from 63 data points (21 evaluators $\times$ 3). The twelve samples were classified into four feel types: smooth, average, rough, and rumbling. A forecast ranking was calculated using these items. Samples No. 1, 5, 6, 8, 9, and 10 were selected as the signal data from each feel type. These data were used to derive the forecast equation. In order to confirm the accuracy of the forecast calculations, the data of samples No. 2, 3, 4, 7, 11, and 12 were selected as the verification data (target data).

### *8.2.4 Forecast of Feel of Fishing Reel by MT System*

Data analysis was carried out by a pattern recognition method called the T-method in the MT system [12]. The MT system is a synthesis measurement method for creating one scale from the measurement values of multiple dimensions. The method is applied to pattern recognition, assessment, clarification, forecast, and

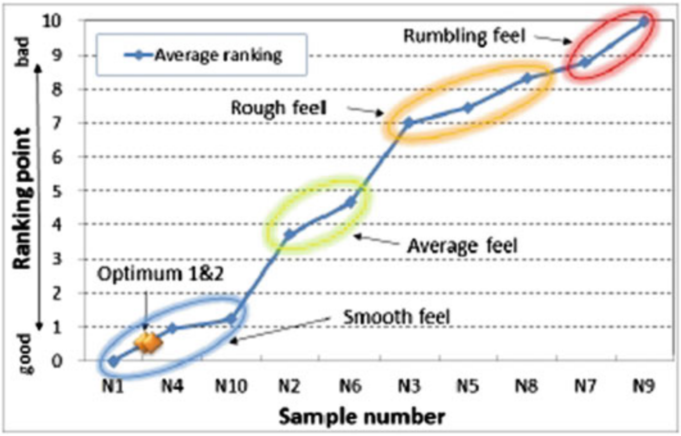



**Fig. 8.6** Classification of ranking point

estimation. Previous papers reported the application of the MT system to the evaluation of a gear device [13]. Moreover, the MT system employs many types of methods, i.e., MTA method, TS system, T-method, and RT method [12]. With regard to the T-method, a scale is created using a calculated weight according to the SN ratio of each measurement value. The SN ratio represents the ratio of the size of the desirable factor effect (i.e., signal) to the size of the undesirable factor effect (i.e., noise). The purpose of this study is to predict the ranking point using the TE measurement results and make an evaluation based on a score. The inspection process is carried out using score ratings. Therefore, in this study, the T-method was selected rather than an abnormality judgment method such as the RT method.

Figure 8.7 shows the concept of the MT system. The symbol “×” in the figure shows the center of the unit space which represents a homogeneous dataset such as those for normalcy and average. The data that deviate from the normal space are regarded as abnormality data.

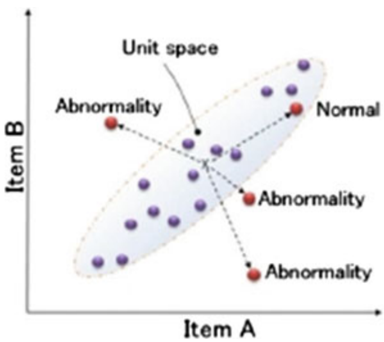



**Fig. 8.7** Concept of MT system

Fig. 8.8 Results of forecast using target data

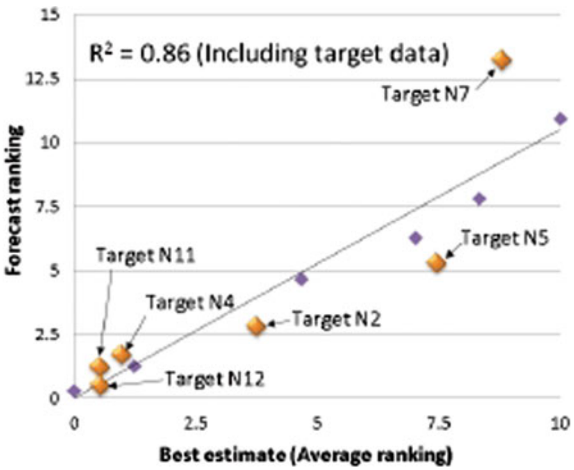



Figure 8.8 shows the forecast results obtained using signal and target data. The $x$-axis represents the best estimate (average ranking), and the $y$-axis represents the forecast ranking. It was confirmed that there was a high correlation between the best estimate and the forecast ranking. The square of the correlation coefficient was 0.86. In this manner, the forecasting method was established. In addition, the square of the correlation coefficient for each item was calculated using these results. It was confirmed that the TE amplitude of the concave tooth flank was responsible for 82% of the forecast and, therefore, had the strongest influence on the feel of fishing reel.

## *8.2.5 Conclusions*

The vibration felt by a user on the handle of the spinning reel is very slight, and its measurement is considered very difficult. This study elucidated the relationship between this slight vibration and the vibration based on the gear-pair engagement. Thereby, the previously vague sensory human judgment was quantified and a new method for sensory human assessment in industrial products was proposed.

(1) The feel of fishing reel was evaluated and predicted using the accurately measured, by the T-method, TE waveforms.
(2) There was a high correlation between the best estimate and the forecast ranking. The square of the correlation coefficient was 0.86.
(3) The TE amplitude of the concave flank had a strong influence of 82% on the feel of fishing reel.

## 8.3 Quantification of Feel of Fishing Reel by Vibration Measuring System Using a Bone-Conduction Speaker

### *8.3.1 Introduction*

In the previous section, a quantitative method for evaluating the feel of a fishing reel was established using a face gear pair via a TMM. However, the method cannot evaluate the feel of a fishing reel when the gear pair has been assembled on the reel. This paper discusses how the feel of a fishing reel is evaluated based on the gear-pair vibration when the gear pair has been assembled in the reel. In order to measure the gear-pair vibration, an evaluation method was proposed using a BCS. Sufficient validity of the system is investigated using spectrogram analysis.

### *8.3.2 Vibration Measuring System*

Figure 8.9 shows the configuration of the vibration measuring system. It consists of a BCS (NEC tokin VS-BV201), an amplifier, and a voice recorder. The BCS uses a piezoelectric-type sensor and is attached to the handle knob of the reel. The slightest vibration is measured and converted to sound data which are recorded by the voice recorder.

### *8.3.3 Definition of Best Estimate by Sensory Human Judgment*

A total of five sample reels were prepared for evaluation. These reels were high-end models, and the vibration was smaller than that of normal models. The difference in

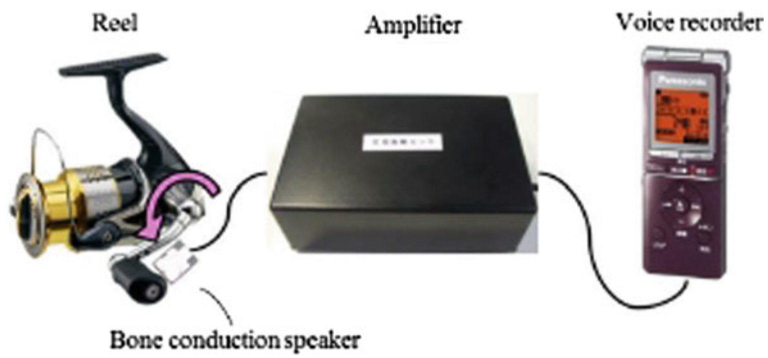



**Fig. 8.9** System configuration of the vibration measuring system

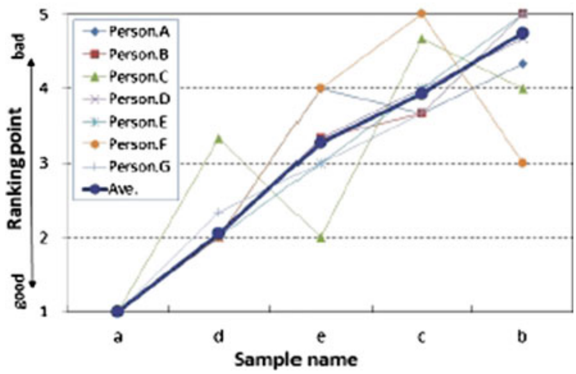
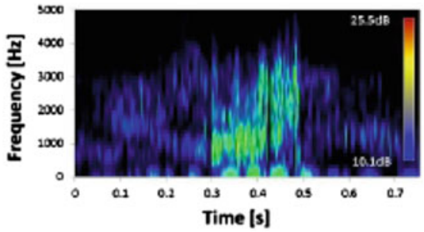



**Fig. 8.10** Ranking of feel of fishing reel

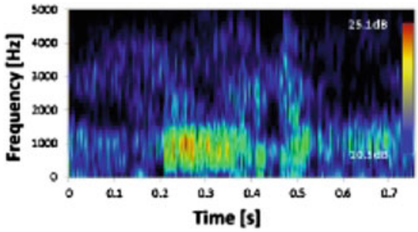
feel between these sample reels was very small, and the evaluators did not experience any discrepancies. The evaluation points were transformed into a ranking, and the feel of these samples was evaluated through sensory human judgment. The evaluators were selected among the twenty-one evaluators mentioned in the previous section. The reel body was held with the right hand, the handle was rotated in 80 $\text{min}^{-1}$ with the left hand, and a metronome was used to ensure that the handle rotated at a substantially uniform rotational frequency. The sound data were recorded for 20 s each. Figure 8.10 shows the results of the sensory human assessment by the seven evaluators, three times each. The $x$-axis represents the sample name, and the $y$-axis represents the ranking point. This average ranking from 21 data (7 evaluators $\times$ 3) represents the best estimate.

### 8.3.4 Verification of Vibration Measuring System

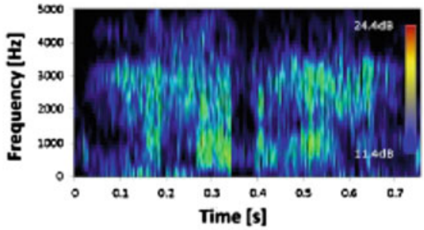
The recorded data were analyzed by spectrogram analysis (KTH WaveSurfer 1.8.8p3). Figure 8.11 shows five sample results. The $x$-axis represents time, and 0.75 s is the time needed for one full handle rotation. The $y$-axis represents the frequency of sound. The color in the graph represents a power spectrum obtained by an FFT (fast Fourier transform) analysis; red color suggests large power spectrum. These graphs are arranged from small ranking point to large ranking point, i.e., samples—a, d, e, c, and b. It was found that the graphs of samples—e, c, and b—have more red-to-yellow-colored regions compared to the graphs of samples—a and d. In the graph of sample-b, significantly more red-to-yellow-colored regions were found in the high-frequency band. This result corresponds to the ranking shown in Fig. 8.11 and suggests that the system can distinguish slight vibration differences in high sensitivity.



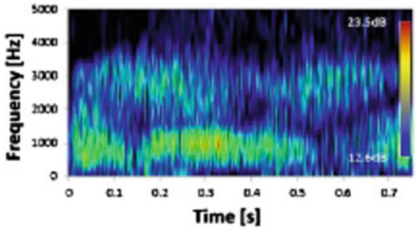

(a) Sample-a (1.0 point)



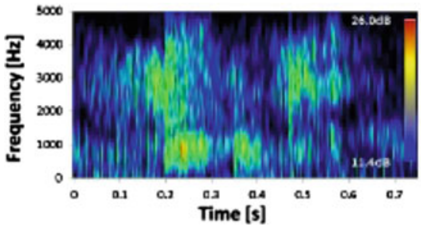

(b) Sample-d (2.2 point)




(c) Sample-e (3.3 point)




(d) Sample-c (3.9 point)




(e) Sample-b (4.7 point)

**Fig. 8.11** Result of handle vibration by spectrogram analysis

### *8.3.5 Conclusions*

In order to measure the gear-pair vibration when the gear pair has been assembled on the reel, an evaluation method was proposed using a BCS. Thereby, it becomes possible to make a quantitative assessment using a reel product.

In addition, during the evaluation an inspector can hear the vibration sound, similar to the feel of the fishing reel conducted from the handle, amplified from a speaker. Consequently, the evaluation becomes easier and its accuracy improves dramatically.

(1) An evaluation method using a BCS was developed as the vibration measuring system.
(2) The system can distinguish slight vibration differences at high sensitivity.
(3) An inspector can hear the vibration sound amplified from a speaker, similar to that of the feel of fishing reel conducted from the handle.

## 8.4 Development of Vibration Simulator and Equal Vibration Curve

### *8.4.1 Introduction*

In the prior section, it was reported that the feel of a fishing reel depends strongly on the amplitude of the TE. The results indicate that the feel of a fishing reel will improve if the accuracy of the tooth flank is improved. For this purpose, it is necessary to introduce a high-accuracy machine tool, which results in increased production costs. As already mentioned in the previous section, twelve sample face gears were used for the evaluation of the feel of the fishing reel. However, face gear samples are very expensive. Therefore, experiments such as these cannot be carried out frequently. Furthermore, there are four types of receptors under the skin of the fingertip [14–16], i.e., “Meissner’s corpuscle,” “Pacinian corpuscle,” “Merkel’s disk,” and “Ruffini ending,” which have been described in the handbook of physiology [17]. The Pacinian corpuscle [14, 18, 19] is most sensitive to vibration, which contributes to the acceleration sensor [14]. It has been confirmed that the feel of the fishing reel changes according to the rotational speed of the handle. The results show that it could be possible to improve the feel of the fishing reel by controlling the mesh frequency without changing the tooth flank accuracy. In order to evaluate the feel of the fishing reel, a vibration-generating machine (vibration simulator) was developed instead of using commercial products. The relationship between a mesh frequency, based on the gear-pair vibration, and the feel of the fishing reel was investigated using the vibration simulator.

### *8.4.2 Development of Vibration Simulator*

Figure 8.12 shows the system configuration, which consists of a speaker (outer diameter = 23 cm) [20], an amplifier, a power source, and a personal computer

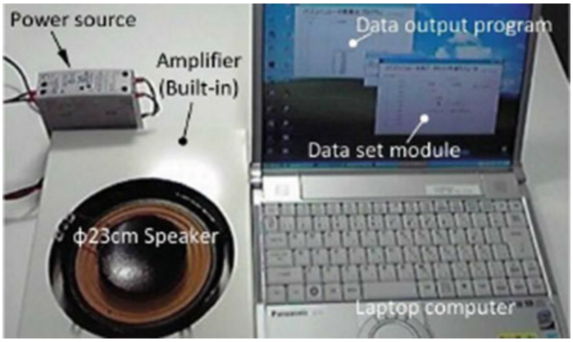



**Fig. 8.12** Configuration of the vibration simulator

(PC). When one of the datasets is selected, the system outputs a corresponding vibration from the speaker for 2 s. The vibration feel is evaluated when the fingertip touches the speaker. Using this system, a reliable evaluation becomes possible without having to consider other factors such as the change in the rotational speed or uneven rotation of the handle.

### 8.4.3 Derivation of Equal Vibration Curve

In the case of acoustic sensitivity, it is widely accepted that the magnitude of sound that humans can feel differs with the frequency even if the sound pressure level is constant [21]. The equal loudness curve is derived from the relationship between the sound pressure and frequency. Sound sensitivity is at maximum value when the frequency is around 4000 Hz. Concerning the tactile sensitivity, there are some studies on the equal vibration curve such as the equal loudness curve with respect to a thumb, middle finger, and index finger, respectively [22–25]. However, the feel of a fishing reel is evaluated using three fingers (thumb, middle finger, and index finger) in which a handle is grasped lightly. Therefore, we try to comprehensively derive the equal vibration curve (equal sensation contours for vibration curve) from the assessment results of the two fingers (middle and index finger). The vibration level is defined as the feel of the fishing reel. Even if amplitude differs, a vibration that feels the same is regarded as a vibration of the same level. The equal sensation contours for the vibration curves are derived by changing the vibration frequency and amplitude. Figure 8.13 shows the derived equal sensation contours for vibration curves. The $x$-axis represents frequency and the $y$-axis half of the amplitude.

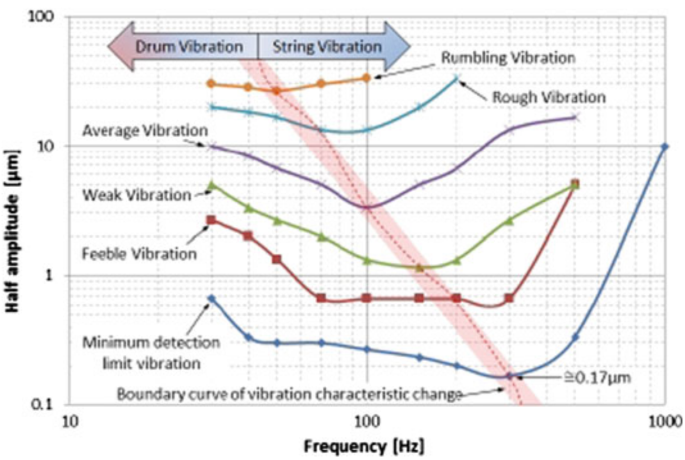



**Fig. 8.13** Equal sensation contours for vibration curves

The vibration curve limit represents the level where a vibration is not felt at all and sensitivity is at the maximum for a frequency of 300 Hz. The results suggest that the vibration frequency in which a tactile sense becomes sensitive is 300 Hz. Therefore, humans experience a bad feel of the fishing reel around 300 Hz even when the amplitude is the same. According to the experimental results for the thumb, Verrillo [22], or the middle finger, Stevens [23], the frequency at which tactile sensitivity is at the maximum (peak frequency) is identical for each vibration level for the equal vibration curve. However, Fig. 8.13 indicates that the peak frequency decreases as the vibration level increases. The vibration feels are divided into two categories based on the peak frequency, i.e., those similar to a percussion instrument (drum vibration) in low-frequency band and those similar to a string instrument (string vibration) in high-frequency band. The string vibration is more comfortable than the drum vibration. Consequently, it was confirmed that there is a nonlinear relationship between the tactile sensitivity of a finger and the vibration frequency.

### *8.4.4 Conclusions*

In the previous section, it was reported that the feel of a fishing reel is highly correlated with the TE waveform. A vibration simulator was developed in order to investigate this correlation in detail. The relationship between the amplitude and the frequency was investigated using this simulator. Consequently, it was possible to study the relationship between the tactile sensibilities of the fingers and the vibration without prototyping a face gear pair.

(1) The equal sensation contours for the vibration curve were derived by the vibration simulator.
(2) The peak frequency maximum differs for each vibration level, and the peak frequency decreases when the vibration level increases.
(3) The peak frequency derives the vibration feel like a drum in low-frequency band and like a string in high-frequency band.

## 8.5 Study of the Vibration Pattern

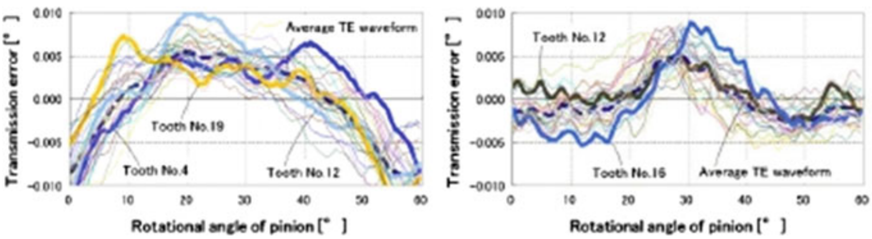
### *8.5.1 Introduction*

In the prior section, it was confirmed that there is a nonlinear relationship between the tactile sensitivity of human fingers and the vibration frequency. This result indicates that the feel of the fishing reel improves if the mesh frequency shifts from the peak frequency to the low or high frequency without minimizing the vibration amplitude. However, the analysis considered only the relationship between the mesh frequency and the amplitude in terms of a sine wave vibration. By comparing the sine wave with the measured TE waveform, we found that the two parameters were not similar. The results show that other nonlinear relationships might exist. Concerning the acoustic sensitivity of a human being, reports have been presented about the relationship between the acoustic sensitivity and the sounds emitted by a gear pair [6–8]. The sound was classified into four categories, i.e., loudness, sharpness, roughness, and fluctuation strength. However, no report on the relationship between the tactile sensitivity of a human finger and the gear-pair vibration exists. We carried out a pattern classification of the measured TE waveforms and the relationship between the TE of the classified patterns, and the vibration feel was investigated using the vibration simulator.

### 8.5.2 *Classification of Vibration Patterns*

The graphs in Fig. 8.14a show examples of actual TE waveform. Figure 8.14a shows the normal rotation, and Fig. 8.14b shows the reverse. The thick dashed lines represent the average TE waveform. The fine lines represent the TE waveform of each tooth. When each tooth waveform was individually observed, we were able to confirm that different vibration patterns occurred compared to the average TE waveform. Figure 8.14a shows some typical TE waveforms for the various vibration patterns. Tooth No. 12 in Fig. 8.14b has larger amplitude than the average TE waveform. In Fig. 8.14a, the peak point of tooth No. 19 is shifted to the left side while for tooth No. 4 is shifted to the right side. Teeth No. 12 and 16 in Fig. 8.14b have a small high-frequency component. The vibration patterns were classified into six types of fluctuation components (Fig. 8.14).

The *x*-axis represents the rotational angle of the pinion and the *y*-axis the amplitude. The thick line in Fig. 8.15 represents the sine wave, which is regarded as the basic waveform. Figure 8.15a shows the amplitude fluctuation in which the amplitude of the basic waveform increases and decreases. Figure 8.15b shows the waveform fluctuation in which the basic waveform transforms into a sawtooth waveform, a pattern in which the peak point moves to the right or left. Figure 8.15c




(a) Normal rotation (b) Reverse rotation

**Fig. 8.14** Graphs of the converged TE waveform

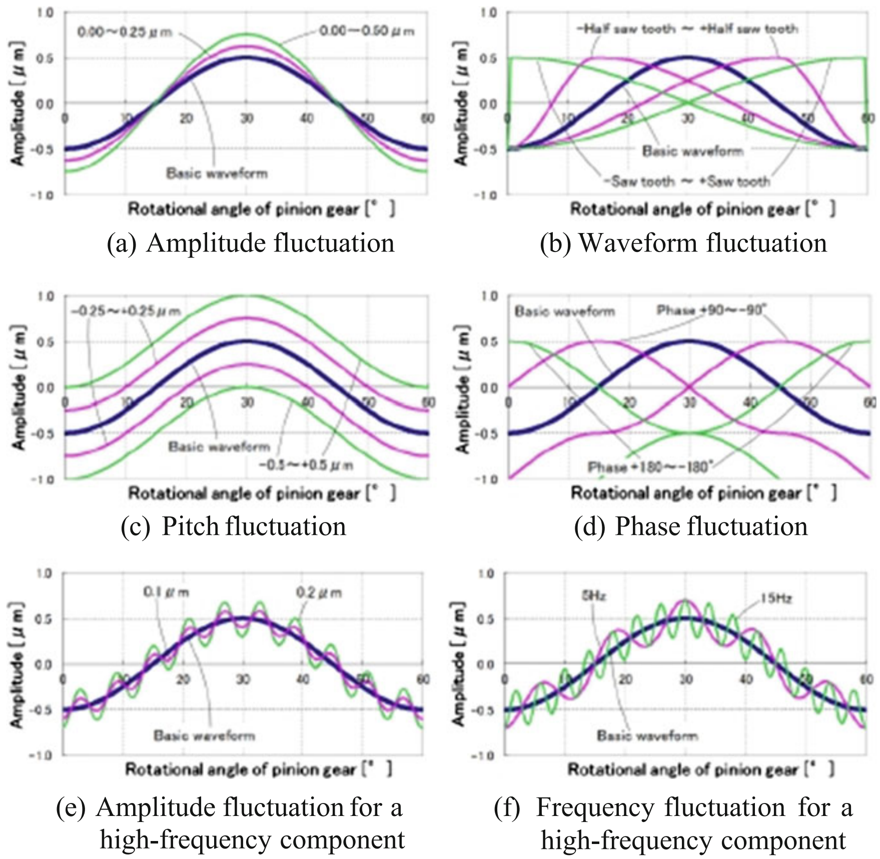



**Fig. 8.15** Classified vibration patterns

shows the pitch fluctuation, a vibration pattern in which the basic waveform moves up and down and corresponds to the pitch error. Figure 8.15d shows the phase fluctuation, in which the phase of the basic waveform changes. Figure 8.15e, f shows the vibration patterns with high-frequency components in the basic waveform. Figure 8.15e shows the amplitude fluctuation for the high-frequency components, and Fig. 8.15f shows the frequency fluctuation for the high-frequency components.

### *8.5.3 Design of Experiment*

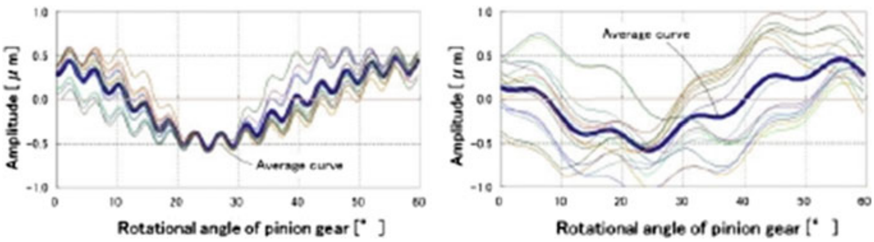
In order to investigate the feel of the fishing reel using the vibration simulator, the simulator is required to output a realistic vibration similar to that of a commercial

**Table 8.1** Design of experiment with an $L_{18}$ orthogonal array

| | Factor name | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| **A** | Range of random number generation | 1/3 | 1/2 | |
| **B** | Range of amplitude fluctuation (μm) | 0.00 | 0–0.25 | 0–0.50 |
| **C** | Range of waveform fluctuation | 0° | ±90° | ±180° |
| **D** | Range of pitch fluctuation (μm) | 0.0 | ±0.25 | ±0.5 |
| **E** | Range of phase fluctuation | 0° | ±90° | ±180° |
| **F** | Amplitude fluctuation of high-frequency component (μm) | 0.0 | ±0.1 | ±0.2 |
| **G** | Frequency fluctuation of high-frequency component (Hz) | 5 | 10 | 15 |
| **H** | Number of teeth on face gear | 24 | 30 | 36 |

product. The aim is to reproduce the dispersion of the TE waveform of a commercial product in the simulator by providing random fluctuation to a basic waveform in the range of a set level. Table 8.1 lists the design of the experiment for an $L_{18}$ orthogonal array and represents the combination of the experimental control factors and their levels. The control factors were selected with a view to investigate the influence of fluctuation, and their levels were selected based on the differences with the commercial products. Eighteen types of experiments were conducted in accordance with these combinations. Six fluctuation components are presented (from B to G) in Table 8.1.

The range of the random number generation and the number of teeth on the face gear are factors A and H. Figure 8.16 shows an example of two generated converged waveforms. Figure 8.16a, b shows the results for combinations No. 11 and No. 16, respectively. By comparing Fig. 8.14 with Fig. 8.16, we were able to confirm that both graphs show a similar trend. The 18 waveforms were ranked three times by the most accurate evaluator, among the 21 evaluators, as shown in the previous section. This ranking represents the best estimate of this evaluation. Two vibrations were selected at random, as a 2 s output, and compared.




(a) Combination No.11 (b) Combination No.16

**Fig. 8.16** Graphs of the converged waveform

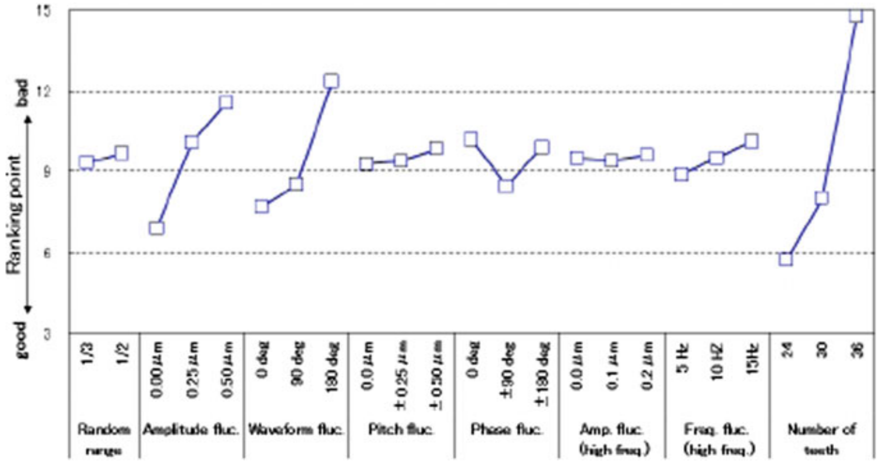



**Fig. 8.17** Response graph of factorial effects

### *8.5.4 Result of the Experiment*

Figure 8.17 shows the response graph that represents the factorial effects. The *x*-axis represents each control factor and level and the *y*-axis the ranking point. The results show that the vibration feel received a significant influence from the amplitude fluctuation, waveform fluctuation, and the number of teeth on the face gear. When the amplitude fluctuation was large, the waveform assumed a sawtooth shape, the number of teeth increased, and the ranking point worsened. We inferred that as the mesh frequency increases so does the tactile sensitivity. Considering all factors, the fluctuation in the mesh frequency showed the largest effect. Thus, we confirmed that a change in the mesh frequency exerts a significant influence on the ranking point.

### *8.5.5 Conclusion*

In order to investigate the relationship between the tactile sensitivity of a human finger and the gear-pair vibration, the vibration patterns with TE waveforms were classified into six types of fluctuation components. The influence on the vibration feel was investigated using the $L_{18}$ orthogonal array. We confirmed that the vibration patterns influence the vibration feel.

(1) The amplitude fluctuation and number of teeth on a face gear significantly influence the vibration feel.
(2) The waveform fluctuation showed that not only the amplitude but also the waveform has influence on the vibration feel.
(3) The increase in the number of teeth has a negative effect on the vibration feel.

## 8.6 Development of Virtual High Mesh Frequency Vibration-Generating Face Gear

### *8.6.1 Introduction*

In the previous section, it was confirmed that the feel of the fishing reel depends on the mesh frequency. Furthermore, the vibration can be divided into two categories depending on the peak frequency. Based on this result, a possibility was discovered where the feel of the fishing reel may be improved if the mesh frequency gets higher than the peak frequency. However, a small module or a large outer diameter is required to attain a high mesh frequency. In the case of a small module, the gear strength would weaken while in the case of a large outer diameter the reel size would increase. In this study, a new method of tooth flank modification was proposed. It is possible to increase the mesh frequency while keeping unchanged the module size and the outer diameter of the face gear. In this method, several grooves were added along the contact curve on the tooth flank of the face gear as shown in Fig. 8.18. Several methods toward vibration reduction by tooth flank modifications have been reported [26, 27]; however, no report on the tooth flank modification by adding grooves on the tooth flank exists.

If the number of vibration could be reached twice per tooth, the mesh frequency would double. The resulting vibration gives an illusion of high mesh frequency to the tactile sensitivity of the finger. In addition, if the number of vibrations increases, the mesh frequency will increase beyond the peak frequency and the feel of the fishing reel will change from a drum vibration to a string vibration. Thereby, the feel of the fishing reel might be improved by the effect of high frequency. To elucidate the effect of the grooves, the relationship between the feel of the fishing reel and the groove was investigated using the vibration simulator. In this report, the suitable number of the grooves has been investigated.

### *8.6.2 Design of Number of Grooves*

The waveform assumes that the vibration occurs when the pinion and face gear with grooves engage. In order to simulate the actual vibration feel, the waveform was

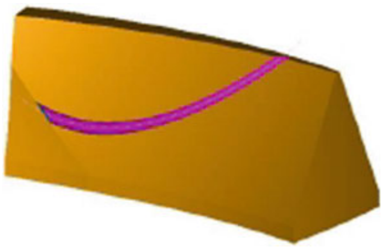


**Fig. 8.18** Additional groove on tooth flank of face gear

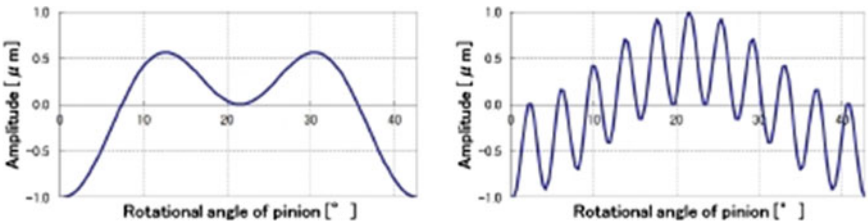


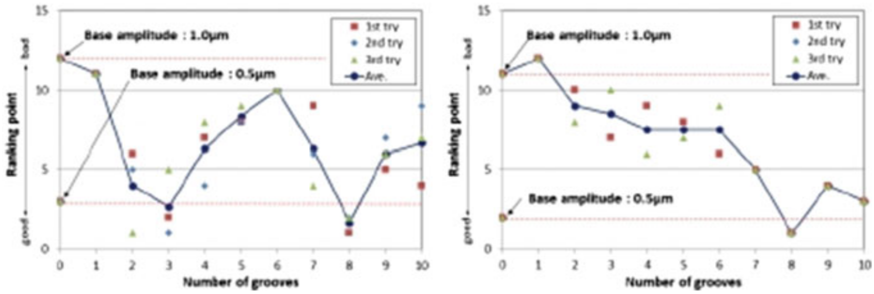

**Fig. 8.19** Vibration waveforms for experiment

broken down to two types. One is the basic waveform caused by the tooth flank deviation and assumes that the tooth flank deviation occurs as sine waveform. The other one is the groove waveform caused by a high-frequency component based on the effect of grooves on the tooth flank, and it also assumes that the vibration waveforms occur as sine waveform. In the experiment, the sine waveform with half amplitude of 1 μm was defined as the basic waveform. The high-frequency component [i.e., number of face gear teeth × (number of grooves + 1)] with half amplitude of 0.5 μm was added to the basic waveform. Eleven cases, based on the number of grooves, were examined from 0 to 10. In addition, the sine waveform with half amplitude of 0.5 μm was used for comparison. A total of 12 waveforms were generated, and Fig. 8.19 shows examples of those waveforms. The *x*-axis represents the rotational angle of the pinion, and the *y*-axis represents the amplitude. In this experiment, the vibration feel was assessed by the most accurate evaluator, three times by each one of them, similarly to the previous section. The ranking numbers were determined one by one through evaluation, and this process was repeated until all the TE waveform sets were ranked.

### 8.6.3 Result of the Experiment

Figure 8.20 shows the experimental results of ranking. Figure 8.20a shows the graph in which the number of the face gear teeth was set to 68, and Fig. 8.20b shows the graph in which the number of teeth was 31. The *x*-axis represents the number of grooves and the *y*-axis the ranking points. The thick blue line represents the average of the triple experiments. The results confirmed that the ranking point changes with the increase in the number of grooves. However, this change has a nonlinear relationship. Therefore, there is an optimum number of grooves for every number of teeth on the face gear.

However, when focusing on the vibration frequency instead of the number of grooves, it is confirmed that the ranking point becomes smaller when the vibration frequency is within the same frequency bands. Figure 8.21 is a synthesis of Fig. 8.20a, b. The experimental results for 50 face gear teeth were also added in the




(a) Number of face gear teeth: 68 (b) Number of face gear teeth: 31

**Fig. 8.20** Influence of the number of grooves on vibration feel

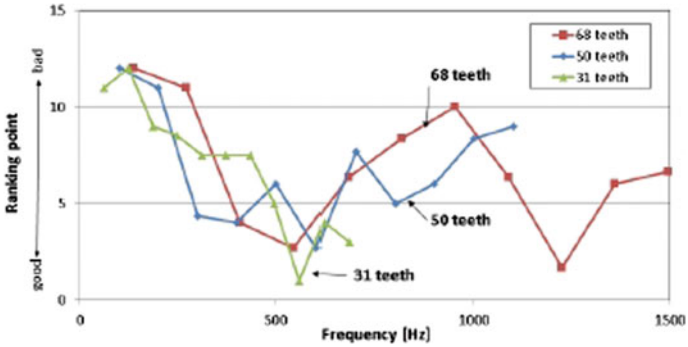



**Fig. 8.21** Influence of the virtual mesh frequency on the vibration feel

graph. The $x$-axis shows the vibration frequency, i.e., (number of grooves + 1) × (number of teeth on a face gear) × (number of handle rotation per second), and the $y$-axis shows the ranking points. Consequently, it was confirmed that the ranking point becomes smaller when the vibration frequency is set to approximately 550–600 Hz.

## 8.6.4 *Conclusion*

A new method was proposed in order to increase the mesh frequency while keeping the module size and the outer diameter unchanged. In this method, several grooves were added on the tooth flank of the face gear and the influence on the vibration by these grooves was investigated using the vibration simulator. As a result, it was confirmed that the vibration feel was improved by applying a proper number of grooves.

(1) The ranking point changes due to the increase in the number of grooves.
(2) There is an optimum number of grooves for every number of teeth on the face gear.
(3) The ranking point becomes smaller when the high-frequency components based on the grooves are within the same frequency band.

## 8.7 Conclusion of This Study

### *8.7.1 Comprehensive Summary of This Study*

In the case of the fishing reel, the most important function is its feel. In this study, we tried to improve the feel of fishing reel in two ways. The first was the quantification of the feel of the fishing reel by detecting slight vibrations. The second was an elucidation of the relationship between the vibration felt by the fingertips and the tactile sensation. Consequently, we obtained the conclusions mentioned in this section.

The first section was an introduction and described the background and objective of this research.

The second section reported the quantification of the feel of the fishing reel based on the TE waveform of the face gear pair measured by the TMM. As a result, the feel of the fishing reel was estimated based on the ranking and measurement results by the MT system. For further details, see author's study [10].

The third section reported the quantification of the feel of the fishing reel based on the handle vibration of the reel measured by the vibration measuring system using a bone-conduction speaker. As a result, the feel of the fishing reel was quantified based on the measurement results of the spectrogram analysis. For further details, see author's paper [28].

The fourth section reported the relationship between the vibration felt by the fingertips and the tactile sensation. A vibration simulator was developed to simulate the vibration instead of using reel products. The relationship between amplitude and frequency based on the sine wave vibration was elucidated. For further details, see author's study [29].

The fifth section reported the research on waveform components of vibrations based on commercial reel products using the vibration simulator. As a result, the relationship between fluctuation components and the tactile sensation felt by the fingertip was elucidated. For further details, see author's study [29].

The sixth section reported the research on a tooth flank modification of a face gear to improve the feel of the fishing reel. The possibility for improvement of the vibration feel was indicated by adding grooves on the face gear tooth flank. For further details, see author's paper [30].

The seventh section is a comprehensive summary of the present study and contains suggestions for future research.

### 8.7.2 Conclusion of This Study

Based on the results of this study, two objectives were achieved:

1) The quantification of the feel of the fishing reel by the detection of slight vibrations
2) The elucidation of a relationship between the vibration felt by the fingertips and the tactile sensation.

In the first case, quantification of the feel of the fishing reel was achieved by a TMM that had a rotary encoder with 1 s resolution and a vibration measuring system with a high-sensitivity piezoelectric sensor.

In the second case, the feel of the fishing reel improves when the mesh frequency is beyond the peak frequency of the tactile sensitivity of human fingertips. A face gear that generated a virtual high mesh frequency by the addition of grooves on a tooth flank was researched using this phenomenon. Thereby, a possibility to improve the feel of the fishing reel was found without minimizing the amplitude of TE.

Academically, we achieved two outcomes. The first was the quantification of the sensory human judgment. It is well known that the sensory human judgment is difficult to quantify because the accuracy level is under a sub-micrometer. The sensory human judgment is quantified by replacing dimensions and theory. Thereby, a method concerning the sensory human judgment was proposed for industrial products. The second outcome was the establishment of a relationship between the tactile sensitivity and the TE, based on the study of the gear vibration felt by the human fingertips. Thereby, a design method was proposed for industrial products using gears.

The fishing reel is a luxury product; therefore, there is no limit in performance levels that enthusiasts could demand from a reel. Improving performance of the reel by only improving the accuracy of the gear will lead to a price increase. The increased price could deteriorate consumer satisfaction. In this study, we researched the gear vibration and the feel of the fishing reel and we achieved academic and technological results that would satisfy consumers without depending on the gear accuracy.

Enjoying fishing is a valuable opportunity to interact with nature. In addition, it is a cultural activity that stimulates human sensitivity. Providing a fishing reel that satisfies the angler is the social contribution of this paper. Technically advanced anglers can feel if it is water turbidity or the behavior of a fish from the change of the feel of the fishing reel. This requires a reel that does not let the angler feel when two metals are engaged. In order to realize such a reel, an advanced gear technology and research toward elucidating sensitivity are indispensable. The technology and research results obtained from this study could be a useful feedback for various current products seeking to improve their sensitivity.

### 8.7.3 Future Research

In reel fishing, anglers wind up a fish with manual force. There are also electrical reels, which wind up a fish with the use of a motor. However, an angler enjoys bargaining with the fish. As long as an angler winds up a fish, an acceleration (gear) system exists that can wind up the fishing line more efficiently. Moreover, as long as the angler rotates the handle of the reel, which includes the gear system, the demand for more feel of the fishing reel never runs out. Until now, the ultimate feel of a fishing reel which could satisfy the most demanding anglers was considered to be no vibration and no noise. However, in this study we considered human sensitivity and we found that there is an ultimate feel of the fishing reel beyond the absence of vibration.

Concerning the sound, we know that noise is uncomfortable but we also know that silence is not the ultimate sound. There is music beyond silence. Similarly, there should be comfortable vibration beyond the absence of vibration. If the angler feels a silky vibration from the reel handle, the reel will stimulate the angler's sensitivity. As a proposal for further research, we would like to enhance the technology obtained in this research by crafting a face gear system which could create such a silky vibration.

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# Chapter 9
# Mental Stress-Performance Model in Emotional Engineering

**Mengting Zhao, Daocheng Yang, Siyun Liu and Yong Zeng**

**Abstract** A wide variety of research topics on emotional engineering has demonstrated that emotional engineering has attracted a lot of attention recently, and more researchers have realized the importance of emotion in engineering. Some of the efforts are focused on the application of emotion to different phases within a product lifecycle, namely conceive stage, design stage, realize stage, and service stage; other efforts are aimed at proposing emotion-based approaches like Kano model and Kansei engineering, where related psychological mechanisms (e.g., the expectation effect theory, categorization of emotion in psychology) are explained. All of the above-mentioned research considered emotion as an important element in the process of product design that aims to help customers to achieve better performance in product use. Still, there is a need to build up a strong causal connection between emotion and engineering. The Yerkes–Dodson law indicates that performance is related to mental stress following an inverted U shaped curve (Wilke et al. in Public Productivity Review, 9(4):342–356, 1985 [73]; Yerkes and Dodson in Journal of Comparative Neurology and Psychology, 18(5), 459–482, 1908 [75]). In applying the law to engineering, it is proposed that factors affecting mental stress lie in perceived workload, knowledge, skill, and affect (Nguyen and Zeng in J Integr Des Process Sci 16(3):65–88, 2012 [45]). In this chapter, we aim to fill the gap between emotion and performance in existing literature on emotional engineering with the mental stress-performance model.

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## 9.1 Introduction

Emotion is essential for humans [20, 50]. Richard S. Lazarus once described emotions as "*complex, patterned, organismic reactions to how we think we are doing in our lifelong efforts to survive and flourish and to achieve what we wish for ourselves*" [36]. Human beings are born with emotions which happen every second in one's daily life whatever they do and wherever they are. A student may feel happy when he gets an A in a course after continuous hard working, while a teacher may feel disappointed when lots of students fail to answer his/her question. The employer may be satisfied with the performance of his employees, and employees may feel excited about the news of salary increase as a return. A child can be anxious waiting for his parents after breaking a flower vase, and the parents could get upset when they see the fragments on the floor. Psychologists have long pondered the nature of emotion, measurements of emotions, the mechanism of emotion and its relationship with cognitive aspects and behavioral performance [21, 30, 36, 43, 57]. Some psychologists divided emotional states into positive and negative moods and then compared participants' behavioral responses under different moods [14, 28]. Raghunathan and Pham pointed out the different influence of anxiety and sadness on decision-making, even though those two emotions were both classified into negative moods [55]. Numerous studies have been done exploring the influence of emotion on mental stress, purchasing behavior, performance in decision-making, and so on [5, 7, 37].

Engineering in the twenty-first century differs from traditional engineering. The term engineering can be loosely defined, "especially in Great Britain, as the manufacture or assembly of engines, machine tools, and machine parts" [65]. S. Fukuda mentioned that the engineering in the twenty-first century is changing as design has changed from designer-centric to user-centric in [26, 27]. That is to say, the purpose of engineering is to satisfy customer's needs instead of inventing tools to solve a specific problem [19, 58]. This difference in understanding reflects an increased emphasis on customer's feelings and user experience (UX), which also results in a series of user-centered products. For example, the emerging human-centered industry, affective computing, and emotional design have been attracting considerable attention in recent years [47, 53]. Extensive research has been conducted to improve the quality of human–computer interaction (HCI) by making computers capable of understanding users' emotions [35, 70]. Even some ordinary goods sold in the market may be products of emotion-based engineering. Whether we admit it or not, the idea of emotional engineering has already been implemented into various aspects of our life.

The influence of emotion on engineering will be investigated through a literature review of emotional engineering. Different stages within the entire product lifecycle are discussed separately hoping to acquire a good understanding of how emotion participates in engineering. Given that a product lifecycle can be divided into four major phases including conceive, design, realize, and service [54], a literature review of emotional engineering is developed in the order chronologically corresponding to lifecycle phases. In addition, a lack of theoretical support for emotion-performance relation in existing research works on emotional engineering is pointed out through our review. Further efforts are required to address this theoretical deficiency so that the influence of emotion to engineering can be well analyzed.

Aiming at introducing emotional factors into engineering, the first task is to detect emotion. Emotion recognition is attracting considerable attention in recent years thanks to advanced technologies such as the possibility of using electro-physiological signals [41, 56]. Researchers and engineers have then succeeded in using those obtained emotions to provide customers with better products and services [1]. But the lack of explicit explanation of the causal relationship between emotion and engineering is still challenging most of those works.

With the extracted emotional factors, the final goal is using them to control and improve the quality of emotional engineering. The remainder of this work is organized following the mentioned logic. Section 9.2 reviews emotional engineering studies and points out the problem of lacking theoretical support for emotion-performance relation. Regarding the mentioned theoretical deficiency, the theoretical model entitled mental stress-performance model as well as other candidate models are presented in Sect. 9.3. The mental stress-performance model, which was first proposed by Nguyen and Zeng [45], was selected to be the foundation of our study based on a series of discussions. Afterward, in Sect. 9.4, we apply the model to some emotional engineering studies according to the analysis of potential obstacles in the application of the model. Several successful application examples are presented in this section which not only confirm our choice, but also show its feasibility in explaining emotion-performance relation. A general procedure of integrating the model into emotional engineering was finally summarized. Section 9.5 presents the conclusion.

## 9.2 Literature Review

According to some existing theories, there are states of emotions associated with varying degrees of "physical and psychological changes that influence our behavior [17, 59]". Some emotions may have more obvious bodily expression for their consequence than other emotions. For example, it seems to be easier to recognize the occurring emotions like anger and excitement from a person than calm and satisfaction. Emotions can produce different physiological, behavioral, and cognitive changes which lead to numerous studies of emotion recognition. Scholars endeavored to recognize emotions by analyzing facial expressions, voice, gestures, as well as human physiological signals collected from sensors like heart rate variability (HRV) and electroencephalography (EEG) [23, 49, 78].

Emotion not only contributes to the communication between human beings but also plays a critical role in rational and intelligent behaviors [52]. For example, Byeon and Kwak presented a 3D convolutional neural networks to recognize people's emotions by detecting successive frames with facial expression images through video camera in [11]. The authors indicated that emotion recognition technologies were needed for robot to make proper emotional move fitted to situation. Among various technologies, they focused on video-based facial expressions recognition technique. Speech emotion recognition has been an attracting topic for decades [40, 60]. Wang et al. proposed a Fourier parameter model for speaker-independent speech emotion recognition [69]. An emotion recognition methodology was introduced in [79] using short time speech analysis. In such studies, researchers agreed on the importance of speech in human communication as well as the necessity to improve the quality of human–machine interaction (HMI). Emotion, one of the huge differences between humans and machines, could be the key to achieve their goal of making "natural and smart" HMI. Appelhans and Luecken presented in their work a theoretical and empirical support for the emergence of HRV as an important marker of regulated emotional responding [3]. The authors believed that emotion could guide our decisions and involve changes in behavioral tendencies. According to their analysis, HRV was a "*promising physiological index of emotion regulatory ability*." Similar to HRV, EEG signals were supposed to be reliable in recognizing emotions; as a result, research has been conducted on EEG-based emotion recognition [39, 46].

Most of these studies discovered the importance of emotions in various engineering aspects in different lifecycle phases. However, few researchers have offered clear explanations on how exactly emotions contributed to providing better solutions in engineering design. This may be due to the reason that researchers in the traditional studies of emotion paid more attention to its components and their corresponding processing mechanisms [16, 21, 24, 51, 57]. Therefore, studies on emotion applying to different phases in a product lifecycle are discussed in the following subsections.

### *9.2.1 Conceive/Design*

Let us first talk about how emotion participates in early stages within the product lifecycle. The engineering design process is usually considered to include the conceive stage, design stage, and part of the realize stage within a product lifecycle [13, 29, 68]. Therefore, in the following, we may use design to represent the combination of conceive phase and design phase.

In the book entitled *Emotional Design*, the author Donald A. Norman has divided the emotional interactive process between products and users into three levels, namely visceral level, behavioral level, and reflective level [47]. Those three levels have further been mapped to product characteristics in this book as follows:

Visceral level → Appearance
Behavioral level → Pleasure and effectiveness of use
Reflective level → Self-image, personal satisfaction, memories

The first level is about initial reactions and is easy to understand as people tend to be attracted by "pretty" things. Thus, physical features (shape, color, texture, and sound) dominate at this level. Good-looking appearances of products are expected at the first design level with the purpose of drawing customers' attention and forming a positive first impression as well. Different from the first level, some features like functionality and usability of products are considered at the behavioral level. Therefore, an excellent user experience of operating the products is the most important issue. If the visceral and behavioral levels are about "now," the reflective level extends much longer. Furthermore, people's self-identity is located at this level.

Here is a good example of how those three aspects work in Norman's book [47]. When Motorola asked Herbst LaZar Bell to design a headset for coaches of the National Football League, the design team felt it challenging at the beginning. First of all, this headset should be "cool" and comfortable so that coaches would like to wear it. Secondly, the headset should be solid enough considering that football games may sometimes be played in extreme temperatures and under bad weathers. In addition, coaches tend to experience violent mood swings during one match, and in some cases, they may throw it to the ground. Another problem is the requirement of high communication quality given that it is always used in a noisy environment. Lastly, the headsets should satisfy the coaches in a long term by projecting a heroic, strong, disciplined image of the leaders who managed the world's toughest players. The designers finally succeeded in making such a headset, but the design process was long and tough. As the author wrote in the book [47], "*Sophisticated computer-aided drawing tools that allowed the designers to visualize just how the headset looked from all angles before anything had been built, optimizing the interaction of ear cups and microphone, headband adjustment, and even the placement of the logos (maximizing their visibility to the TV audience while simultaneously minimizing it to the coaches, to avoid distraction).*" In this case, emotional factors were taken into consideration through satisfying customers with all their requirements. The designers understood the importance of users' emotion in making good design work, but they failed in explaining how exactly emotions affect.

Another example of emotions participating in design is the study revealing the relationship between drivers and head-up display (HUD) image designs [64]. In the first experiment, seven design elements, such as forms for major content and image size, were extracted from the collected HUD images. Through applying the Taguchi method [66] to create the six representative samples and using factor and cluster analysis, five representative pairs of Kansei words were finally extracted from the pool of Kansei words [42, 61]. Then in the second experiment, the relationships between the five Kansei words and the extracted design elements were identified using the quantification theory type I (QT1) method. It seems that only the first two emotional design levels have been discussed. In this study, the authors have applied category classification, which was one type of Kansei engineering to find the target relationship. They did not directly explain to readers how emotions influence performance, but they left us with the possibility of finding answers by conducting deeper study in Kansei engineering. One sentence in the article goes as "*Kansei engineering can be used to determine consumers' emotions from a psychological basis*" [66].

Widiyati and Aoyoma evaluated the relationships between PET bottle shapes and customers' impressions in [72]. Robust design of Taguchi method was applied in order to obtain the optimal combination of design elements based on users' impressions. Similar to the HUD image design example, Kansei words were also collected and further reduced to express customers' emotions. Afterward, six design elements were extracted. In terms of aesthetic design, Kano model was used in the next step to recognize product performance which could improve customers' aesthetic satisfaction [8]. They also provided a software system which served as an intelligent tool for designers with the proposed design method implemented. In this study, different types of emotions were taken into consideration as numerous Kansei words were selected. The whole work has focused on how to design the PET bottle shape with higher aesthetic value which is supposed to give benefits not only to customers but also to the industries themselves. The methodology was presented in an organized manner with details, whereas the perspective which served as the foundation of this research was curtly described as "*when a product can satisfy customers' emotion, the product will give deep impact to the owner, and as a result, it will be treasured by the owner*." What we can figure out from this sentence is the authors' awareness of explaining the influence of customers' emotion on their own performance, but unfortunately they failed to give enough support.

What we can conclude from those examples is that the customers' emotions are considered during the process of design activities. The same conclusion could also be found in other works [2, 48] that are not discussed in this chapter. Satisfaction is treated as the most important emotion of customer in this kind of studies, while some researchers and designers consider other emotion types as well. When applying emotional factors to design process, some researchers use existing models and technologies where the explanation of emotion-performance relation could possibly be found. Other researchers did not mention this relation at all. Therefore, an explicit explanation of how customers' emotions affect the final performance is missing in those studies.

### *9.2.2 Realize*

It is proposed that emotional factors participate through different ways in this phase, which involves how a product is manufactured, made, built, procured, produced, sold, and delivered. Several examples are discussed in the following paragraphs. In [80], the authors have introduced users' emotions into the product manufacturing and production process. They first highlighted that the concept of product quality could be divided into objective and subjective aspects, among which the subjective quality is hard to be quantified as subjective characteristics strongly rely on users' individual perception and emotions. Besides, they figured out the necessity of linking the spontaneous emotions to a long-term context such as the attitudes of users. Finally, a new methodology named ACADE was proposed in their work, abbreviation for Application for Computer-Aided Design of Emotional Impression, which combined interdisciplinary knowledge of users' long-term evaluation system and preference choice together. The influence of customers' emotions on product quality was discussed from different point of view, but an explicit descriptive model or mathematical explanation of the emotion-quality relation was extremely demanded.

A new emotion-based TV quality rating system was presented in [1] to replace the conventional rating system which had only considered the audience size. The objective was to make the program better "sold" with good quality by using the results of the rating system. This BROAFERENCE rating system collected emotional cues through "automatic detection of facial expressions and gaze information via a camera observing the audience" [1] watching a certain TV program, thus it could enable measurements of the quality of the TV program other than the audience size. And Facial Action Coding System (FACS) [15] was applied to analyze audience's emotional experience like happiness, surprise, and so on.

Shuichi Fukuda discussed how to provide "best fit product" in [25]. Except for topics like production, other interesting aspects related to producing "best fit product" were also mentioned, including building up product-user trust, satisficing, and degradation. Among them, the idea of "satisficing" or "satisfy enough" was proposed by Simon [63], indicating that if a customer was satisfied enough, the product would be good even when its functions were not good enough. Trust and satisficing here belong to emotional factors, and efforts have been conducted in explaining their influence on "best fit product." Whereas, we believe in the possibility of making it a more complete and more convincing work by introducing an appropriate emotion-performance model.

### 9.2.3 Service

Interactions or communications between product and user usually occur at this final phase of the lifecycle. This service phase can be interpreted as use, maintain, support, retire, disposal, and so on. In order to study emotional product-user communication, our strategy is to start from how emotion participates in human-human communication and then proceed it to product-user communication.

Emotions have always been playing an important role in conventional communications in humans, and it seems very natural as human is born with emotions. When a person is talking to someone else, we can tell if his or her response is appropriate or not although there are no criteria for right or wrong judgments. Therefore, good communication or emotional communication only happens when emotional factors are well considered [31, 50]. Emotional human–computer interaction (HCI) has gained increasing attention because of the ubiquity of computers [6, 12, 32]. It concentrates on communication between computer and human, where the product is specified as computer. It is a big challenge to make computers capable of coping with human emotions and then react properly. The same difficulty also confronts human–robot interaction and human–machine interaction [4, 33, 38]. We believe that examples of emotional application in those aspects can better explain the participation of emotion in service phase with specified product.

Yamashita et al. developed several HCI systems which might improve the quality of emotional communication in [74]. Some of their systems were supposed to make HCI pleasant and natural by selecting and displaying facial expression on the screen, such as the example of e-mail application. Moreover, attentions were also paid to verbal communications, where HCI could be optimized by making computers repeating the user's utterances and chiming in with the user. The purpose was well conveyed which was to make HCI pleasant and to encourage the user to continue talking. Facial expressions were believed to make HCI friendly, and the authors' systems were made to repeat sentences given that "repeating the other person's utterances, and so on, can sometimes encourage him/her to continue speaking, give pleasure to the communication." The user's emotions were considered in this work, but the lack of theoretical support is rather obvious, especially for repeating sentences where the authors took a common phenomenon as the reason. This work could be more convincing if how computer's repeating behavior affects people's performance is explained.

For example, the concept of integrating emotional competence into robotic system was elaborated in [18], where robot was the only studied product. A fuzzy emotion model was proposed serving as the basis for recognizing emotions and representing static aspects of robot's emotions. And the studied emotions in this work were restricted to four basic types of emotions, namely happiness, sadness, anger, and fear. Facial expressions were collected and analyzed for emotion recognition. The authors then explained how artificial drives and emotions were used to control the behavior of a robot. In the end, a novel robot head MEXI was proposed as an application of their concepts. Equipped with this MEXI system, robots were able to react in different ways according to the results of emotion recognition, which consequently improved the quality of communication. In this work, the authors discussed that the drives were important factors influencing the emotional state of humans from a psychological point of view. As a result, positive emotions tend to arise under a long-term satisfaction of a drive and vice versa. Therefore, we can say that the theoretical foundation of making robots communicating humanlike was explained. But how does this kind of emotional communication affect the emotional states of human, the other side of the human–robot communication?

Many studies [52, 71] revealed that people also seemed to admit that the more computers or robots act like a real person, the better the quality of communication is. For this reason, focuses were always drawn to the process or mechanism of how human emotion is generated during HCI communication hoping to make "smart" computers with emotions and emotional expressions. Results from the research seem convincing, whereas some theoretical support is missing from the beginning. Why is making humanlike computer so important? What is the exact relationship between the "smartness" of computers and communication quality? If we assume that the quality of communication can be reflected by human willingness of speaking and sharing ideas, then how does humanlike computers affect human performances? And we hope to solve it by relating changes of human emotions to his potential performances when communicating with such an "emotional robot" or "emotional computer."

## 9.3 Model Presentation and Comparison

The necessity for filling in the gap between users' emotional states and their performance can be concluded from the previous section. In other words, emotional factors are considered to some extent aiming at making "good" product without supporting explanations about why such factors are selected and how they correlate to the expected behaviors of consumers. A theoretical model describing the human emotion-performance relationship may be an appropriate tool in solving this problem. With such a purpose, this section introduced a mental stress-performance model proposed by Nguyen and Zeng [45] and as well as some other candidate theories.

### *9.3.1 Mental Stress-Performance Model*

The mental stress-performance model (σ–p model) was developed to study how creativity occurs in design phenomena [45]. In this model, only four factors were identified affecting the occurrence of creativity during the design process, namely perceived workload, knowledge, skill, and affect. Affect, which could be interpreted as emotion, feeling, or mood, was believed to be influential on human performance in creative design through its impact on stress. Consequently, a rational idea emerged: if we could keep all the affecting factors besides affect under control, this model may be utilized as an emotion-performance model to investigate the relation between human emotion and performance.

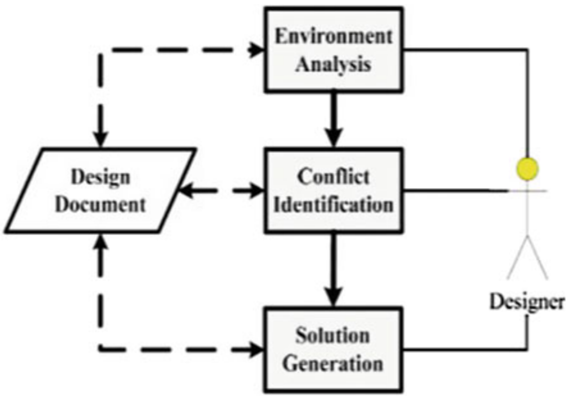
This model took the axiomatic theory of design modeling (ATDM) [76] as its formal tool and two postulates as its first principles. Furthermore, the validation of this model was presented by interpreting the roles of sketching in design, indicating the feasibility of applying this model to design activities. The authors first explained the recursive nature of design process. A design problem could be seen as an initial design state. The goal of solving such a problem was to achieve a new design state by applying appropriate design solutions which were generated from demanded design knowledge to this specific design problem. Once a new design state was defined, a new set of design knowledge would be determined considering its dependence on the design problem.

After that, the relations between different design states were discussed where the design process was believed to have underlying nonlinear dynamics and possible to have chaotic motions. Those discussions resulted in the presence of the first postulate, denoted as the postulate of nonlinear design dynamics. This postulate indicated that the design process could be solved by environment-based design (EBD) [77] as illustrated in Fig. 9.1. They also mentioned in this postulate that design reasoning was sensitive to initial conditions, based on which three routes leading to design creativity were then derived. Those three routes could be briefly described as formulating design problem differently, extending design knowledge, and changing the environment decomposition.

Starting from those identified three routes, the descriptive design model named EBD was once again applied to find the factors that might cause initial conditions to change. It was through mental capacity that the designers contributed to the changes in initial conditions. The second postulate was proposed that correlated designers' creativity with their mental stress during the design process. The famous Yerkes–Dodson law was presented which addressed the relation between performance and mental stress (arousal) which followed an inverted U shape curve as shown in Fig. 9.2. Moreover, designer's mental stress was assumed to be mainly affected by workload and mental capacity in opposite directions. More precisely speaking, mental stress was positively related to workload but negatively related to mental capacity [67]. In this way, factors affecting mental capacity (Fig. 9.3) could be treated as affecting factors to mental stress, namely knowledge, skills, and affect. Among them, the affect referred to emotions or feelings, and it worked by determining how much of one's knowledge and skills could be effectively used in solving problems.

Finally, four major affecting factors were identified including the workload and the three factors affecting mental capacity. This model aimed at helping designers in creative design activities, where creativity was essential and the only performance being studied in their work. Considering that emotion was one of the four major factors which was denoted as affect in the authors' original work, this model could

Fig. 9.1 EBD process model [77]



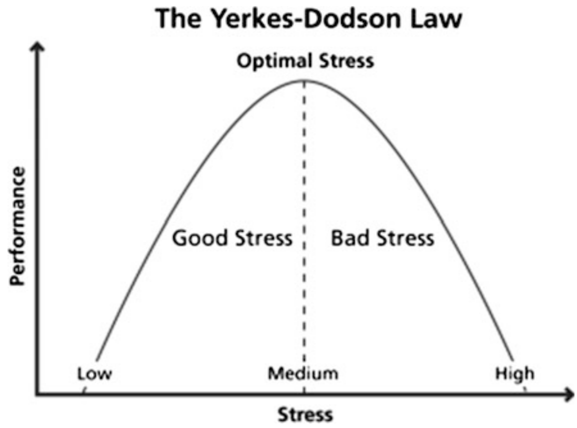



**Fig. 9.2** Inverse U shape relation

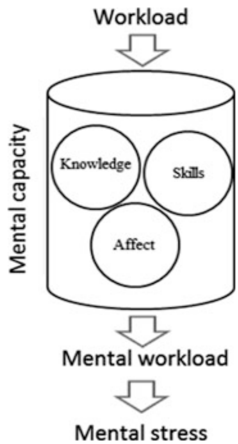



**Fig. 9.3** Factors affecting mental capacity

probably be integrated for the explanation of human emotion-performance relation. Thanks to the Nguyen and Zeng's efforts [45], an explicit relation between designer's creativity and their emotion has been established. The required efforts could not be trivial if we decide to apply this model to other problems concentrating on various kinds of human performances.

## *9.3.2 Other Candidate Models*

### 9.3.2.1 Kano Model

Noriaki Kano integrated product quality with the degree of its performance and the degree of customer's satisfaction [22]. In industrial applications, the application of

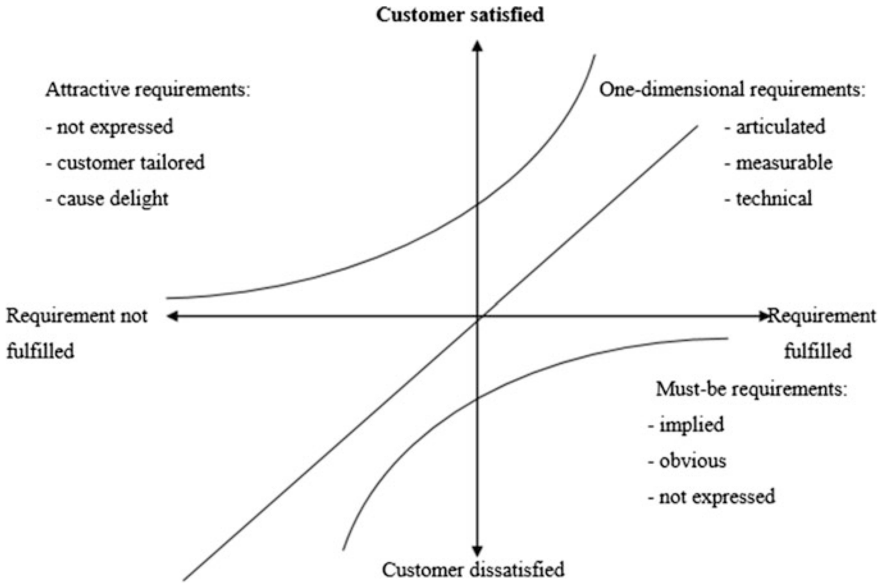



**Fig. 9.4** Presentation of Kano model

such a model seemed helpful to recognize certain performances of products that might improve customer's aesthetic satisfaction.

As we can see from the illustration of Kano model in Fig. 9.4, different requirements of customers would lead to different responses. Those requirements were actually customers' needs which were identified into three categories: basic needs, performance needs, and excitement needs corresponding to must-be requirements, one-dimensional requirements, and attractive requirements, respectively, in Fig. 9.4. This was done by using Kano questionnaire. After that a weight adjustment was assigned based on the results of categorization, aiming at reprioritizing the criteria.

User's emotion refers to their satisfaction toward a product in this case. The significant difference between this model and the mental stress-performance model lies in the understanding of performance. Kano model explains the relation between product's performances and user's emotions, whereas in the other model the relation between user's performance and his own emotions is illustrated. Furthermore, it seems possible and feasible to relate user's performances to the performance of products by combining those two models.

#### 9.3.2.2 Kansei Engineering

The word Kansei refers to feelings, emotions, and impressions in Japanese [44]. Kansei Engineering represents a methodology that correlates the feelings, emotions, as well as "wishes of users with product development, and developing solutions and design parameters" [42]. Six types of KE have been developed, tested, and proved as follows:

Type I—KE Category Classification;
Type II—Kansei Engineering System (KES);
Type III—Hybrid KE;
Type IV—Mathematical KE;
Type V—Virtual KE;
Type VI—Collaborative KE;

Marghani et al. presented their studies of the application of each KE type in [42] indicating that various tools and methods could be used to apply a certain type. For example, the important steps within the KES procedure were listed when explaining the second KE-type KES. In the following step, Kansei database was discussed as well as a case study of Urban Flats.

Briefly speaking, KE is able to identify the features of a product which are the most affective ones to certain target human emotions. In addition, developments and improvements are then conducted based on the results of the identification part. It is somehow similar to Kano model as they both focus on establishing the relation between uses' emotions and characteristics of the product.

**To sum up**, the mental stress-performance model (σ–p model) could work with either of them by helping explaining why certain emotions should be considered, and how such emotions would affect future human performance. According to our review, the majority of this kind of research concentrating on the introduction of emotions into engineering mentioned more or less the relation between users' emotions and product performance. As for the selection of the target emotions, a lack of theoretical support as well as a descriptive model is obvious explaining how human emotions correlate to their own performance. Even though plenty of research works have been conducted to study the emotion-performance relation of human beings [9, 10, 34, 62] from the point of view of psychology and social science, few were suitable for emotional engineering. Therefore, we decide to introduce the mental stress-performance model into studies of emotional engineering. What we expect is that those original studies become more completed and convincing with our efforts on model integration. In the following section, several examples will be discussed to show how this model can be applied.

## 9.4 Application of σ–p Model in Emotional Engineering

Some examples of the application of the mental stress-performance model, as abbreviated to σ–p model, will be discussed in this section. Several questions could be asked to help further understand the model application, such as: What could be the obstacles when applying this model to emotional engineering? What should we keep in mind to succeed in model integration based on the identified obstacles? Once the model is successfully inserted, what would be the advantages? What conclusions could we finally draw from those examples? Before the commencement of discussing model application examples, efforts have been made to explore answers to those questions.

The goal of introducing such a model into studies of emotional engineering is to explain the emotion-performance relation of users when interacting with products. Emotion or affect is the only factor that we are interested in, in spite of other three affecting factors, namely workload, knowledge, and skill.

One problem comes from the fact that other affecting factors should be kept constant or relative constant while emotional factors changes. Furthermore, if they are required to be kept stable, they should firstly be identified under different contexts at the very beginning depending on the target performance. Only in this way will our results reflect an emotion-performance relation directly. Another noticeable obstacle is the quantification of emotional factor and the evaluation of performance. Given the expression of the σ–p model, only the quantified factors are practicable. Thus, during the process of applying this model, efforts should be made to overcome those mentioned obstacles.

Once we succeed, a clear description of the emotion-performance relation will help making the existing studies of emotional engineering more completed through filling the missing theoretical support. Nevertheless, the advantages of introducing the σ–p model are more than that. The successful applications of the model in emotional engineering could support its expanded applicability in other fields and may give modifications to the model in reverse. Furthermore, the quantification of emotional factor will enable a deeper participation of emotion into engineering in the near future.

### *9.4.1 σ–p Model-Aided TV Rating System*

Let us take the BROAFERENCE rating system as an example which was mentioned earlier as an application of emotional engineering within the realize phase in Sect. 9.2. In this study, emotional parameters were extracted by utilizing FACS for facial expressions observed by cameras. The FACS system defined 46 atomic action units, whereas the current proposed rating system considered only a restricted number of action units which indicated happiness and surprise.

In order to apply the σ–p model to it, the studied performance of users here is their willingness to watch a TV program. The required knowledge is little under such circumstance, and identified skills are changing channels, volume adjustment, and other possible TV operations in which every individual seems quite skilled. Then we can start by quantifying the workload as the duration of the program. With those mentioned variables controlled, a relative clear emotion-performance relation is established. For the quantification of emotion, we can distribute different weights to different action units within FACS, and among them AU2 and AU12 get the highest scores. Any possible facial expression could be described by a combination of some of those units. As Nguyen and Zeng once explained the influence of emotion as "affect will determine how much one's knowledge and skills can be effectively used," larger numbers represent better exertion of knowledge and skills resulting in less stress. In addition, TV programs are never too short so that the common goal is to make the stressful audience less stressful. In other words, we can assume that we are working on the right side of the inverse U shape relation between stress and performance where less stress indicates better performance.

The improvements are obvious after applying the σ–p model. The former results of BROAFERENCE are capable to tell good quality from bad quality of TV programs. However, their results are too vague and the reason was not explained for why AU2 and AU12 represent good quality. Combined with the model, the rating results now can be used to rank different TV programs. This means more information could be figured out such as how every TV program is selling and if it is well made in audience's opinion. Theoretical support is also given to correlate their calculated emotional parameters to audience performance, i.e., their willingness to continue watching a TV program.

### *9.4.2 Applying σ–p Model to PET Bottle Design*

We have presented the work of Widiyati and Aoyama [72] to help illustrating emotional engineering occurring in early stages of product lifecycle. As we have pointed out the problem of missing explanation of the emotion-performance relation in former section, we try to solve it by introducing the σ–p model.

In this particular case of PET bottle shape design, the expected performance is that customers purchase such PET bottle and perhaps recommend it to others afterward. In addition, customer's knowledge and skills related to the usage of the PET bottle are easy to control mainly for two reasons. Firstly, the requirements for knowledge and skills in this case are so little that we can assume customers' knowledge and skill levels as constant. Secondly, the changing part is restricted to the shape of the bottle resulting in relative stable product functionality. Moreover, the second reason can also be used in explaining why workload is treated unvaried given that changes in product functionality will increase or decrease the required skills and the workload as well. So we can easily keep those three variables within σ–p model stable and leave emotion the only varying factor. Now we should concentrate on the quantification of customers' emotion. This time we should take the whole inverse U shape curve into consideration which is different from that in the example of TV rating system. That is to say, finding the optimal stress level becomes more complicated than dealing with the relation following a monotonic function. In the authors' original work, weight adjustment of each criterion was performed by multiplying the adjustment coefficient with each Kano category where Kano model was integrated. With the purpose of introducing the σ–p model, we could make use of the criteria obtained from Kansei words analysis. Extreme scores are distributed to each pair of Kansei words under the assumption that the optimum appears as a compromise. For instance, we can fix Masculine at 1 and Feminine at 5 for the Masculine–Feminine pair, and among the numerous methods of finding the optimal value we start by finding the median value for simplicity. Those calculated optimal values will replace the original Kansei points and participate in later steps.

The surprising result is that we find a way to integrate the σ–p model together with Kano model in the PET bottle design. According to our discussion in Sect. 9.3, those two models emphasize on different aspects: Kano model focuses on relating emotional factors to different characteristics and elements of a product; σ–p model, on the other side, establishes the relation between human emotion and his own performance which helps in explaining why certain emotions should be considered regarding a target performance. In the meanwhile, the design workload is not much elevated because what we utilize for emotion quantification has existed already. Therefore, with all those efforts we aim to provide an improved methodology with the complete relation considered which occurs during product-user communication.

### *9.4.3 Summary*

To summarize, the objective of this section intends to integrate the σ–p model into varied applications of emotional engineering. There is a distinct possibility of applying the σ–p model to different emotional engineering studies. In the beginning of this section, we have analyzed some potential obstacles which tend to be important aspects in the process of σ–p model application. Then efforts have been done to integrate the model to TV rating system and PET bottle shape design where a clear human emotion-performance relation is established. Improvements are shown in the completeness of research works as expected.

Furthermore, by combining those examples and former analysis, a general routine of introducing the σ–p model to existing studies can be concluded as follows. Firstly, what should be identified is the studied or target human performance. Secondly, the identification of knowledge, skills, and workload corresponding to a specific performance should be done. Thirdly, we should provide analysis to explain how to keep those three factors stable. Fourthly, the quantification of emotion as well as performance should be discussed which is the key of the whole process. Lastly, explanations are needed to show how this model helps reflecting the emotion-performance relation.

## 9.5 Conclusion

The prime objective of this work is to identify the problem, i.e., the lack of explanation about human emotion-performance relation in most emotional engineering studies, and then to solve it by integrating the σ–p model. In the first place, we point out the problem in existing emotional engineering studies through a brief literature review, which is the lack of theoretical support for human emotion-performance relation. Afterward, the σ–p model, abbreviation for the mental stress-performance model, was presented, and it was believed to be the appropriate model to fill the missing explanation after a series of discussions in Sect. 9.3. As a consequence, what situates in the following part is the analysis together with examples of the σ–p model-integrated emotional engineering studies. Finally, a general routine is obtained to guide the integration of the σ–p model into various studies of emotional engineering within different phases of the entire product lifecycle.

For simplicity, we have divided the applications of emotional engineering into three categories, namely conceive/design, realize, as well as service when reviewing literature works. The highlighted point is that emotion can be introduced into engineering through different methods at any stage within the whole product lifecycle. In most cases, emotion is reflected through product-user interactions no matter how it participates during the realize stage or conceive/design stage. In addition, studies concentrating on emotional communication between product and users within the service phase are not only conducted to improve the service quality but also offer help in future product design and manufacturing process. There is increased dependence between different phases and activities in emotional engineering compared to that within traditional engineering. Researchers' enthusiasm in emotional engineering does not diminish at all despite the increased complexity of relations which surely makes their research more challenging and time consuming.

This study aims at introducing a theoretical foundation for emotional engineering. While in the opposite direction, it also brings us to consider about what further modification could be done to the original σ–p model. The quantification of emotion and performance will still be a challenge. The quantification of the other affecting factors like workload and knowledge should also be considered as we endeavor to establish a general quantification system which could simplify the application of σ–p model in various cases. Considerable efforts are needed in our future work to realize a convenient application of the σ–p model in emotional engineering.

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# Chapter 10
# Walking Assistance According to the Emotion

**Eiichiro Tanaka and Louis Yuge**

**Abstract** A walking assistance device for apoplexy patients has been developed. We developed a walking assistance device RE-Gait®, which assists the motion of the ankle joint while walking. The motor is controlled according to the walking phase grasped with the pressure sensors under the sole. It is already utilized as a product, for the gait training by so many hemiplegic patients. By using the technology of RE-Gait®, a new device for the able-bodied elderly to promote exercise was also developed. This is RE-Gait®Light, which is lower cost, very light, and easy to move. We proposed a new control method for this device, which is automatically tuned according to the condition of the emotion of the user. In this chapter, the evaluation results using this method are introduced.

## 10.1 What Is RE-Gait®?

There are so many apoplexy patients over 1 million in Japan. In past days, it was considered to be impossible for apoplexy patients to recover. However, if the patient starts training immediately after the incident, the brain structure will start to reconstruct, therefore he/she has a high possible to recover compared to no training. That is neuro-rehabilitation. However, the number of the staff in a hospital or a care facility is not enough. Furthermore, in Japan, there is a limit to the hospital admission, therefore, it is hard for patients to continue training with medical staffs.

To address this problem, we developed a walking assistance device "RE-Gait®" [3, 7]. In this chapter, RE-Gait® is explained in detail.

The targeted user of RE-Gait® is a hemiplegic patient; in particular, Brunnstrom stage (Brs) is from 4 to 6. They can walk themselves; however, the toe of the

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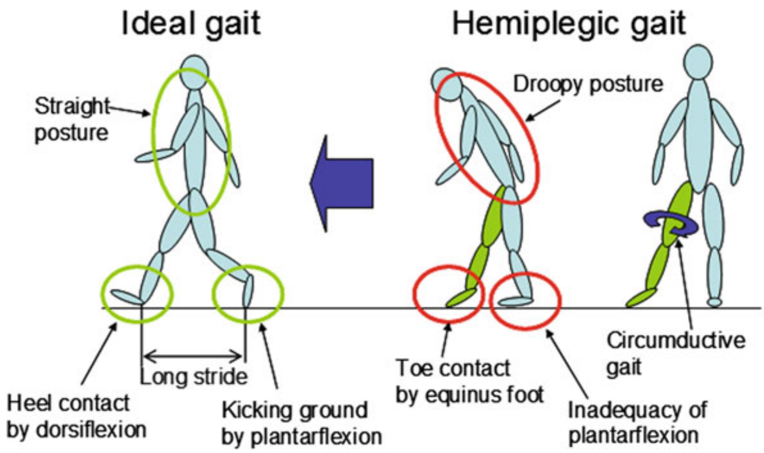


**Fig. 10.1** Comparison between ideal gait and hemiplegic gait

paralyzed leg is extended (equinus foot, Fig. 10.1), because the backward muscles of the lower leg are bigger than forward muscles. Then, at the beginning of stance phase, they cannot contact from the heel to the ground and they contact from the toe. This phenomenon is very dangerous for the patients, because it is very easy to stumble. Furthermore, because the length of the equinus foot of the paralyzed leg is longer than the healthy side foot, they try to prevent to hit the toe to the ground in the swing phase. So the abduction angle of the hip joint becomes very larger than the able-bodied people (circumductive foot). When the patients train to improve their gait, PT (physical therapist) or care staff try to move and raise the ankle joint of the patient. This is very hard work, so RE-Gait® was born as the new device instead of PT or care staff.

Previously, many kinds of walking assistance devices for gait training have been developed by various researchers. Most of them assist a hip joint and a knee joint. However even though able bodied people walk, TA (Tibialis Anterior muscle) is the most fatigable. Because only TA can do the dorsiflexion of the ankle joint. Therefore, we focused on the ankle joint assistance [5, 6].

This device assists only the ankle joint; however, the user can raise his/her leg. Figure 10.2 shows the basic principle of raising the foot. When the medial head of gastrocnemius muscle (GMH) is extended at the end of stance phase, this muscle is diminished by the stretch reflex. GMH muscle is a bi-articular muscle structure, and the knee joint is bent. Furthermore, by bending the knee joint at the start of swing phase, rectus femoris (RF) muscle is also bi-articular muscle and is extended, and then hip joint is also bent as shown in Fig. 10.2. Eventually, the foot is raised by his/her own power.

The structure of the RE-Gait® is shown in Fig. 10.3. Outer and inner flames which are parallel to the lower leg are fixed. The small motor is equipped on the flame, and it can be hidden in the hem of the pants. This motor transmits the torque

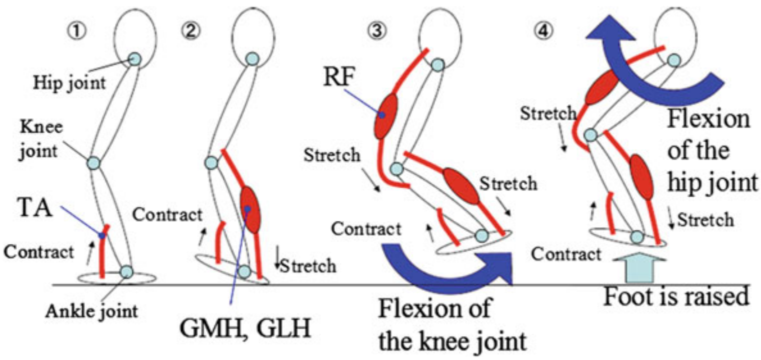


**Fig. 10.2** Equinus foot and mechanism to raise a foot by dorsiflexion assistance


**Fig. 10.3** Photographs of RE-Gait® and tablet software

to another flame which is connected to the sole from outer ankle joint. The sole equips two sensors under the foot. By measuring these two sensor's measured values, the computer can grasp the current walking phase, and then the motor is controlled according to the preset ankle joint variation data. This data has to be set by medical professional's decision from the condition of the targeted user. RE-Gait® is already utilized for so many patients as a product in the hospitals and care facilities. When the PT or user wants to tune it, they can use the touch panel software using a tablet easily as shown in Fig. 10.3, even though they are not an engineer.

## 10.2 Development of RE-Gait®Light for Promotion of Exercise

When the RE-Gait® was started to sell as a medical device, so many people requested that they want to use not only for gait training but also for promotion of exercise. If the device can be used for the elderly to be able to continue walking longer than walking without using it, it can prevent aging and decrease the bedridden population. However, RE-Gait® is developed for patients, so the flames are fixed on the lower leg tightly; therefore, the external and internal rotations of the ankle joint are difficult. Furthermore, the targeted motion is set by the medical professionals. To be able to utilize this device for able-bodied elderly people in the usual life, it has to be low cost, easy to move, and able to tune according to the condition and emotion of the user. By considering these situations, we developed RE-Gait®Light as shown in Fig. 10.4 [6, 9].

RE-Gait®Light can be attached on the user's shoes. It has only outer flame, so the user can rotate ankle joint freely. This device is controlled with Arduino and hobby motor, and it is of lower cost than RE-Gait®. It has two types of control method. One is all-round mode, and the other is walk mode. From the combination of the data of two pressure sensors under the sole as shown in Fig. 10.5 left,

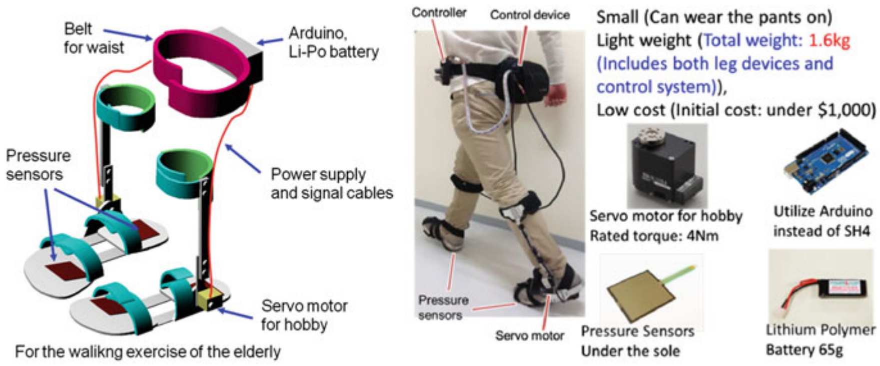


**Fig. 10.4** RE-Gait®Light and used parts

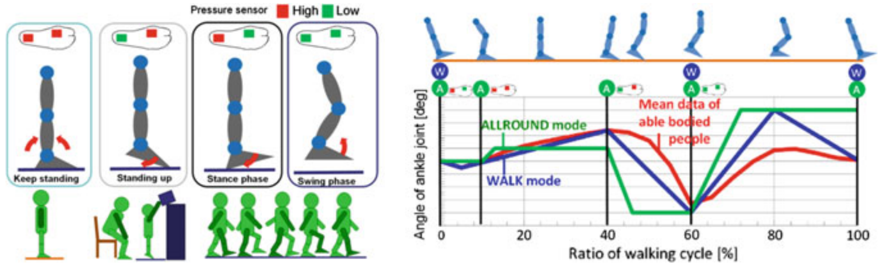


**Fig. 10.5** Comparison of angle variation between all-round mode and walk mode

the device can grasp the current motion and it can assist various motions immediately. However, when the user is walking, this method is necessary to check many times in one walking cycle as shown in Fig. 10.5 right. Therefore, we also developed walk mode, which uses various data; the targeted angle variation, the walking cycle, the trigger setting phase, and so on. Then it can be decreased the number of checking the data of pressure sensors. This method is utilized for both RE-Gait® and RE-Gait®Light.

## 10.3 Experiment of Two-Dimensional Emotion Evaluation While Walking

RE-Gait® is set the targeted values by medical professionals; on the other hand, RE-Gait®Light has to be set by the user. If the user wants to use for promotion exercise, the walking cycle has to be set shorter than his/her normal value or the stride has to be set longer than his/her normal value. However, if the user's emotion is unpleasant and the measured heart beat is too high, this setting is bad for the user. Therefore, the device has to obtain the data of the user's condition and evaluate his/her emotion in each case.

To evaluate the body condition and emotion of the user, we suggested to measure the heart beat; in particular, it is necessary to focus on the variation of LF/HF. LF means low frequency in the range from 0.05 to 0.15 Hz, and HF means high frequency in the range from 0.15 to 0.40 Hz in the frequency analysis result. LF is related to the activity of breathing variation and sympathetic nerve activity. HF is related to the parasympathetic nerve activity. Then, we utilized the variation LF/HF as an indication of arousal or not. However, if this value continues to increase in long time, the subject will be tired. On the other hand, pleasant can be evaluated briefly by using questionnaire, for example, Self-Assessment Manikin (SAM). By evaluating arousal and pleasant, the emotion can be expressed two dimensionally as shown in Fig. 10.6 left [4, 8]. Similarly, walking condition also can be expressed two dimensionally by using the data of the cadence [step/min] and the stride length [m/step] as shown in Fig. 10.6 right [1, 8]. If the relation of the tendency of the sifting vector for each map can be grasped, it will be controlled by the device according to the body condition and emotion. For example, when the current position of the emotion is on the first quadrant in the emotion map, the user will be promoted exercise according to increasing the value of the stride and the cadence. However, when the arousal value is too high, it cannot be continued. Then according to decreasing the cadence, the user will be able to relax. In the case of rehabilitation, it is necessary to improve the gait and try to close to the line of the ratio 0.006 (normal line), because this line shows ideal walking. In particular, rehabilitation is very hard work for patients. If the unpleasant emotion will decrease by controlling the cadence or stride length, the user can continue the training more.

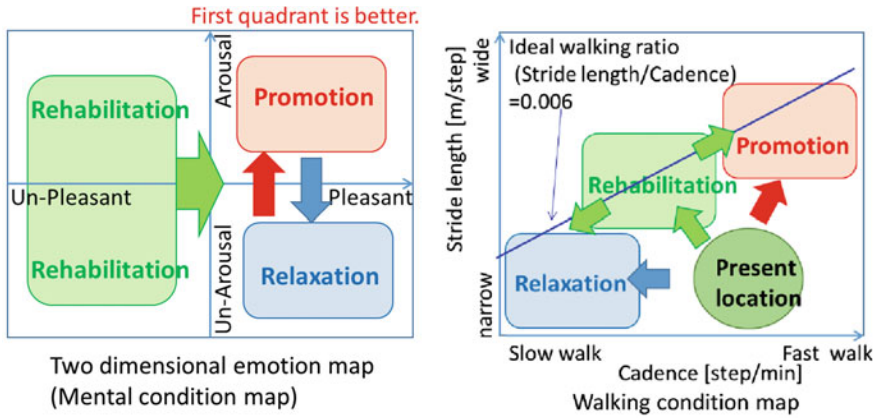


**Fig. 10.6** Emotion map (left) and walking condition map (right)

To confirm this assumption, we carried out the experiment as a pilot test to obtain the relation of these parameters; measured LF/HF variation, questionnaire, stride length, and cadence. Four subjects were able-bodied men (age: 21–22), and we asked them to walk on a treadmill while listening to a beat sound. The basic frequency of the sound, i.e. 100% beat was calculated from the cadence which was determined by the most comfortable walking for each subject. It was previously measured. It was adjusted from 50 to 200% beats gradually by 10% with a tablet computer. While walking and listening to the beat sound, we asked them to tune the velocity of the treadmill frequently whose feeling was comfortable; however, the indication of the velocity was hidden to the subjects.

We defined the result of this questionnaire as the horizontal axis of the two-dimensional emotion map (pleasant). On the other hand, we translated the variation of LF/HF to the vertical axis of arousal, and the value of LF/HF when the subject walked while listening to the 100% beat of the walking cycle was defined as an original point. By using these two parameters, we could define the current position on the two-dimensional emotion map.

Figure 10.7 left shows the measured data of the emotion map for each beat. Horizontal is determined by the data of questionnaire, and vertical is determined by the data of the variation of LF/HF. As a result, when the sound was at 60, 110, 160% beats, the positions of most of the subjects were in the first quadrant (arousal and pleasant). At 180% beat, the positions were in the second quadrant (arousal and unpleasant). At 140% beat, the positions were in the third quadrant (un-arousal and unpleasant). At 90% beat, the positions were in the fourth quadrant (un-arousal and pleasant).

We also made a two-dimensional walking condition map. The horizontal axis is the cadence [step/min], and the vertical axis is the length of stride [m/step]. The cadence and the length of stride which were measured while walking and listening to the beats mentioned above were plotted on the walking condition map. From these results, the similar phenomenon to the shift of the plotted point on the emotional map could be confirmed.

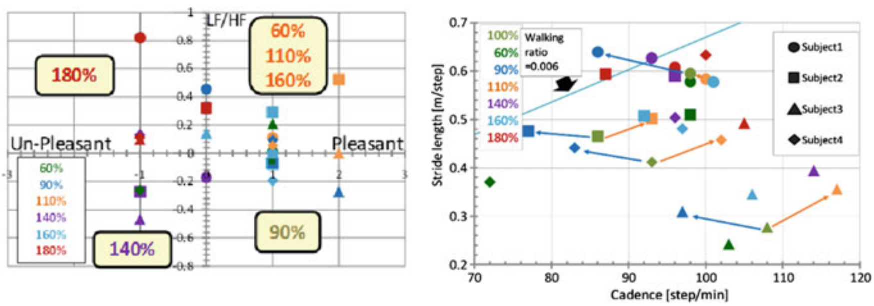


**Fig. 10.7** Measured data in the emotion map (left) and walking condition map (right)

By considering practical use for the apparatus, we focused on the influence changing the cadence set at 90 and 110%. Figure 10.7 right shows the result of point shift on the two-dimensional walking condition map. Light green dots are at 100% of comfortable cadence, orange dots are at 110%, and blue dots are at 90%. As shown in these results, when the beat sound set at 110%, three subjects' stride and cadence increased. On the other hand, when the beat sound set at 90%, all subjects' cadence decreased and stride length increased a little. Therefore, the walking motion is influenced by the beat sound, and even though the walker feels the relax emotion (in the fourth quadrant), he/she increases his/her stride length, i.e. he/she is promoted walking.

From these results, we confirmed the relation between the beat sound and the condition of walking. By looking at this relation, we can suggest the method to keep motivation for gait training of neuro-rehabilitation and promotion to exercise walking.

## 10.4 Control Method According to the Emotion

By using this result, the new control method was proposed as shown in Fig. 10.8 left [9, 10], and the procedure is as follows:

1) The value of BLH (based LF/HF) while walking is previously measured,
2) When the value of LF/HF is over twice of BLH, the targeted cadence of RE-Gait®Light and listening beat sound are tuned at 90% of the comfortable cadence,
3) When the value of LF/HF is lower than the half of BLH, the targeted cadence of RE-Gait®Light and beat sound are tuned at 110% of the comfortable cadence.

In this experiment, subjects were ten able-bodied men and women (age: 21–22), especially in three subjects (subjects 4, 7, 10) usually do the exercise on a daily basis, e.g., going to sports gym or running once or twice per week. The walking experiments were carried out three times on a treadmill as shown in Fig. 10.8 right.

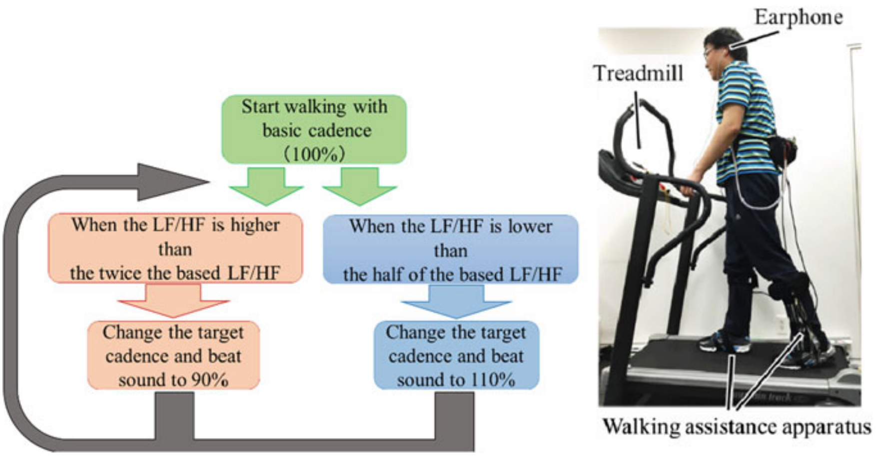


**Fig. 10.8** Control method of the walking assistance and beat sound according to the variation of LF/HF and photograph of the walking experiment

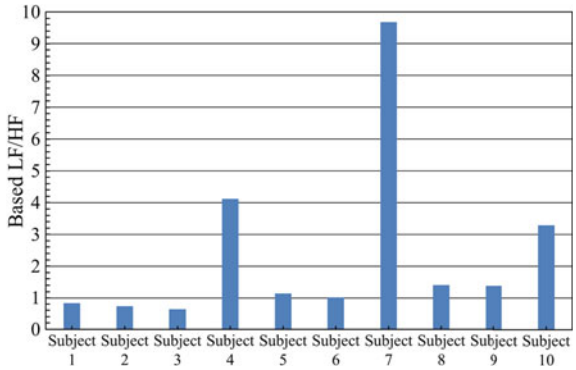


**Fig. 10.9** Comparison of the value of based LF/HF for each subject

First, the LF/HF of the heartbeat was measured while 10 min of normal walk without using the device. Figure 10.9 shows the measured results of the based LF/HF for ten subjects. The results for the subjects 4, 7, 10 are relatively higher than the others. The value of LF/HF can be evaluated by the sympathetic stimulation; therefore, if the people usually do exercise, they can increase the promotion feeling by only walking. Second, after taking enough rest, the LF/HF was measured while 10 min of assisted walk with RE-Gait®Light, whose targeted cadence was continuously at 100%. Finally, after taking enough rest, the LF/HF was measured while 10 min of assisted walk with RE-Gait®Light, whose targeted cadence was changed at 90% or 110%. Figure 10.10 shows the example of the result of the measured variation of LF/HF for the subjects who do not exercise on a daily basis.

From the result, by using the apparatus by tuning the constant targeted cadence and beat sound at 100%, LF/HF decreased than the normal walk without the

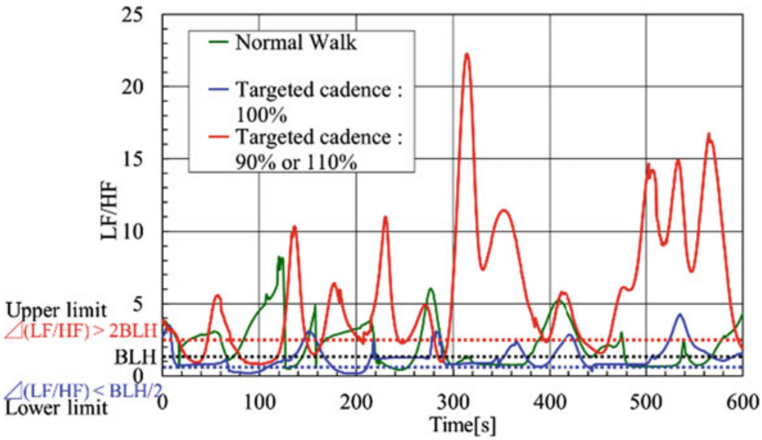


**Fig. 10.10** Example result of the measured variation of LF/HF (Subject 6)

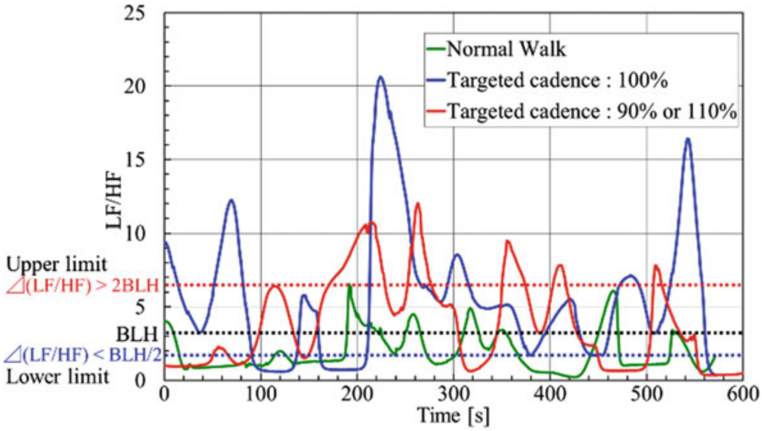


**Fig. 10.11** Example result of the measured variation of LF/HF (Subject 10)

apparatus and beat sound. Therefore, the user can continue to walk with relax emotion. On the contrary, when we utilize our proposed new method which is to change the targeted cadence and beat sound according to the variation of LF/HF, LF/HF increases. Therefore, when the user who does not do exercise usually and he/she wants to promote exercise, this method is effective. On the other hand, in the case of the subjects who do exercise on a basis, the results were opposite tendency as shown in Fig. 10.11. When the targeted cadence and the beat sound set at 100% of comfortable cadence, the apparatus can be activated by the user's excitation. However, when the targeted cadence does not change, LF/HF increased too much. To continue the adequate value of LF/HF, it is better to change the targeted cadence according to the value of LF/HF. As a future work, we have to carry out the experiment by more subjects, especially, the pleasant will be also measured from the body data and evaluate the influence of the walking condition.

## 10.5 Automatic Emotion Evaluation

Finally, as a trial experiment, we tried to evaluate the emotion from the physiological data [11].

As shown in Fig. 10.12 left, IADS in the University of Florida, this is already evaluated by 167 sounds and the average positions on the two-dimensional emotion map from the questionnaire data of listening 100 subjects [2]. By using these data and selected 18 sounds as shown in Fig. 10.12 right, we compared these results and various physiological data, variation of LF/HF, brain waves (α, β), and facial muscles (zygomatic muscle, corrugators muscle) as shown in Fig. 10.13 left. Usually LF/HF has a relation of arousal as mentioned above, α wave has a relation of relax, β wave has a relation of concentration. The facial muscles activity has a relation of pleasant or not by analyzing electroencephalogram (EEG). For example, zygomatic muscle can be evaluated positive feeling, and corrugators muscle can be evaluated negative feeling. When these parameters can be measured and analyzed, we can make automatic emotion evaluation system without using the questionnaire. However, if only one parameter is selected from them and try to utilize for evaluation, each of them has a relatively large error. To decrease the influence of the error and improve the accuracy, we used average and maximum of all data, and utilized clustering, k-means method. As shown in Fig. 10.12 right, we made two groups and divided them in detail. Figure 10.13 right shows the result of clustering. In group 1, three groups could be divided. In group 2, two groups could be divided. From the result, the measured data using IADS far from the axes could be recognized. However,

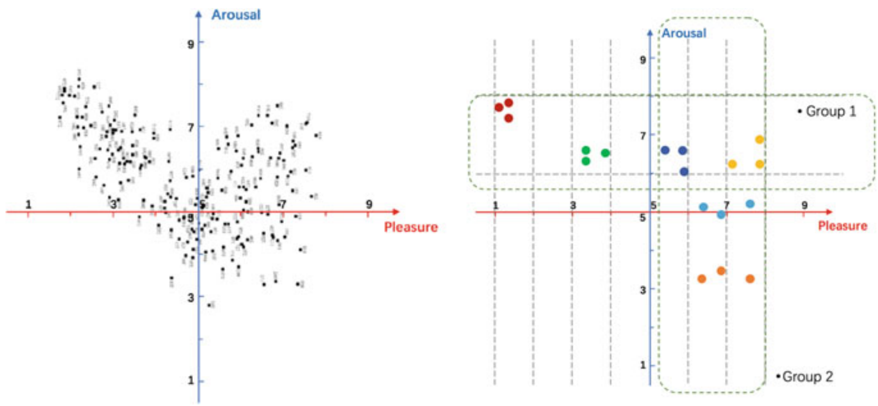


**Fig. 10.12** IADS (left) and the position of the selected 18 sounds

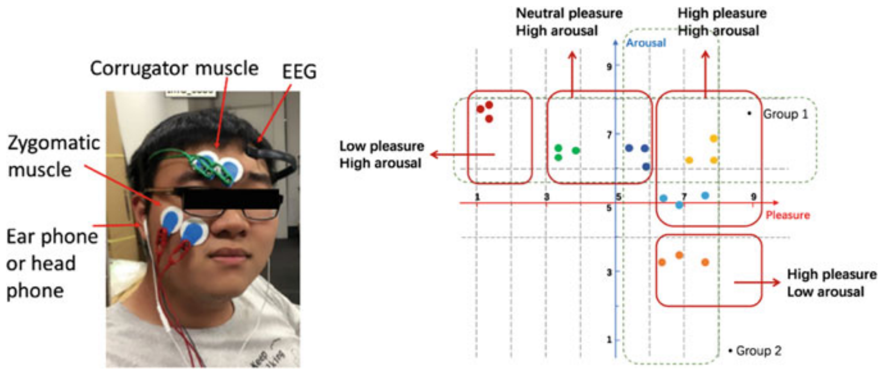


**Fig. 10.13** Attached points on the face and result of clustering

the measured data using IADS close to the axes could not be divided obviously. Now, we are trying to evaluate by using the Mahalanobis-Taguchi method. In the near future, we will show the result of the evaluation and develop the automatic control method for the walking assistance device by utilizing it.

## 10.6 Summary

In this chapter, the walking assistance devices RE-Gait® for gait training of patients and RE-Gait®Light for promotion exercise of the elderly or able-bodied people are introduced. Simultaneously, we found the relation of the tendency of the shifting position between the two-dimensional emotion map and walking condition map. By using this tendency, we suggested the control method according to the emotion, especially, the variation of LF/HF. The result has two opposite types, according to the subjects who were doing exercise usually or not. Finally, we tried the automatic emotion evaluation by using various philological data with k-means method. This method could recognize various emotion areas. To improve, we will try various methods as a future work.

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