Constraints on Synaesthesia

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0. Introduction

Synaesthesia is the phenomenon that involves mapping from one sense modality onto another.[1] For example, *warm color* is a case of synaesthesia, since it involves the mapping from the tactile sense onto the visual sense. This paper introduces a cognitive model called the "Physiological = Psychological" model and discusses constraints on synaesthesia.

1. Synaesthesia and Cross-linguistic Survey

It is well known that synaesthesia shows a certain directionality of possible mappings (e.g., Williams 1976; Yamanashi 1988). Williams (1976: 464), for example, writes as follows:

- If a touch-word transfers, it may transfer to taste (*sharp tastes*), to color (*dull colors*), or to sound (*soft sounds*).
- Taste-words do not transfer back to tactile experience or forward to dimension or color, but only to smell (*sour smells*) and sounds (*dulcet music*).
- There are no primary olfactory words in English (i.e., none historically originating in the area) that have shifted to other senses.
- Dimension lexemes transfer to color (*flat color*) or to sound (*deep sounds*).[2]
- Color-words may shift only to sound (*bright sounds*).
- Sound-words may transfer only to color (*quiet colors*).

Figure 1 shows Williams' generalization. It shows that it is possible for the tactile

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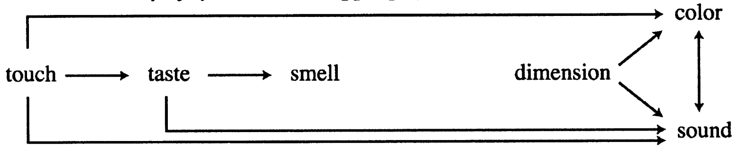
[2] In this paper, we do not discuss dimensional adjectives.

and/or gustatory senses to be mapped onto the other senses, but not in the opposite direction.

Figure1. Directionality of synaesthetic mappings (Williams 1976: 463)



Williams suggests that his generalization is also applicable to explain synaesthesia in other languages. According to his generalization, for example, mapping from the tactile sense onto the visual sense (color) is possible, but not the other way around. On first sight, his generalization might seem to be valid, since, for instance, while those conforming to the possible mapping are found acceptable cross-linguistically (e.g., *re4de yian2se4* [Chinese: 1], *warme kleur* [Dutch: 1], *warm color* [English: 1], *θερμό χρώμα* [Greek: 1], *atatakai iro* [Japanese: 1], *ttatteushan saeg* [Korean: 1]), those conforming to a mapping assumed to be impossible by his generalization are also likely to be found anomalous (e.g., *hong2de wen1du4* [Chinese: 0], *rode temperatuur* [Dutch: -1], *red temperature* [English: -1], *κόκκινη θερμοκρασία* [Greek: -1], *akai ondo* [Japanese: -1], *ppalgan ondo* [Korean: -1]).[3]

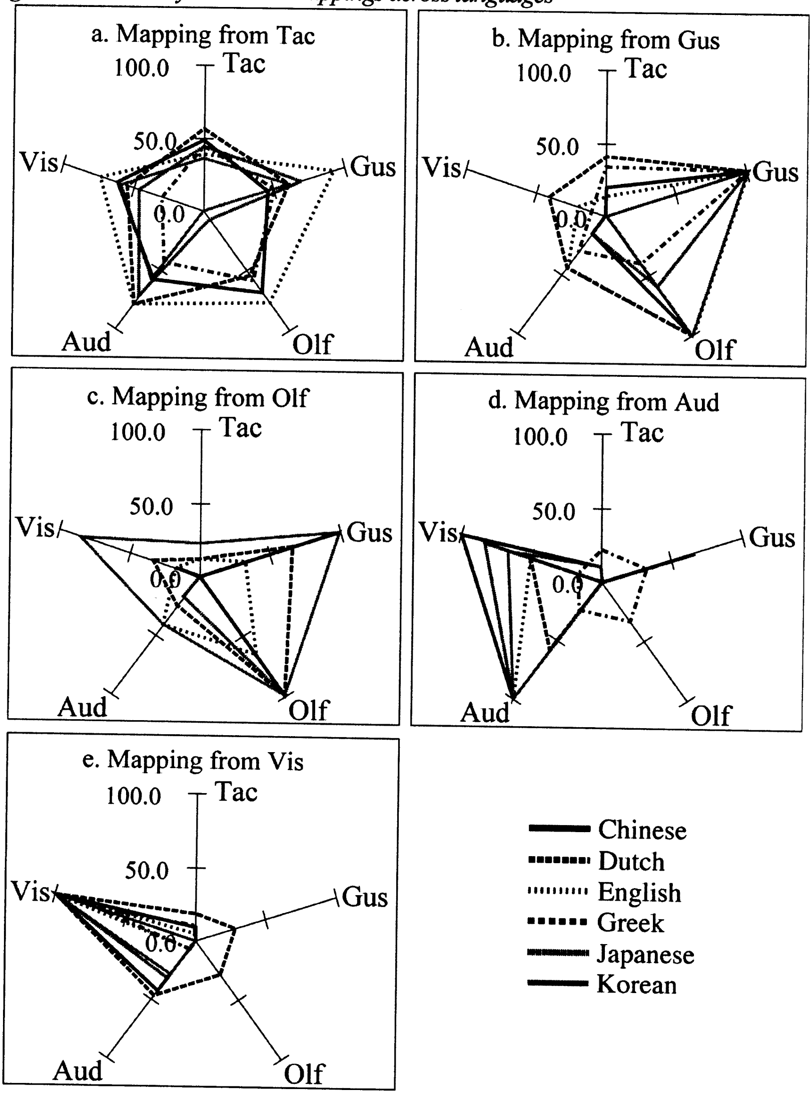
We conducted a cross-linguistic survey. Through careful observation of the results, we will show that Williams' generalization suffers from several empirical anomalies. Our target languages were Chinese, Dutch, English, Greek, Japanese, and Korean. We chose a variety of adjectives and nouns for each sense modality. Words of the tactile sense in English, for example, included the adjectives *soft* and *warm*, and the nouns *touch* and *pain*. The visual sense, for example, included adjectives such as *dark* and *red* and nouns such as *color* and *pattern*. We combined all the adjectives in each sense modality with the nouns in each sense modality. For example, for the adjective *warm*, we made phrases such as *warm touch*, *warm pain*, *warm color*, *warm pattern*, and so forth by combining the adjective with other nouns in all the sense modalities, and then examined the acceptability of the phrases.

In each language, we translated the chosen adjectives and nouns so that they corresponded with those in the other languages. The total number of phrases was 341 in each language (31 adjectives and 11 nouns). We divided the number of possible

[3] In this paper, the level of acceptability is shown by three grades on the basis of the judgments made by our native consultants: 1 indicates high acceptability, 0 acceptable if given a particular context, and -1 very low in acceptability.

combinations by the total number of the phrases in each category. Figure 2 shows the percentage of possible mappings in each sense modality. Examples which are counted as acceptable in order to make these graphs are those judged by the subjects as 1 and 0 on our acceptability grading scale.

Figure 2. Possible synaesthetic mappings across languages



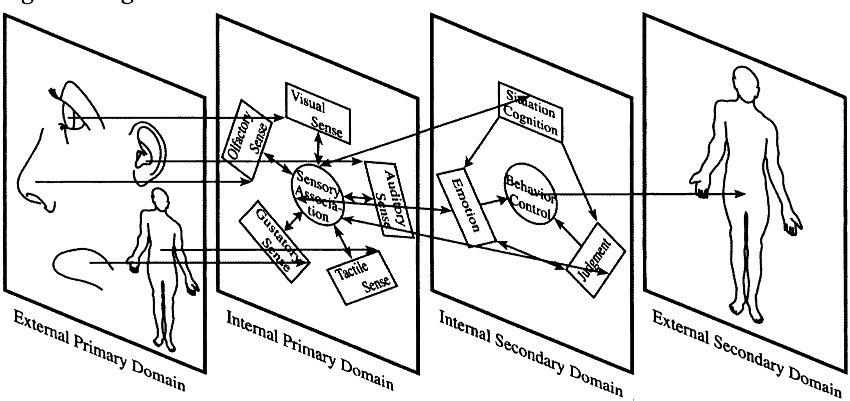
As the graphs show, despite some idiosyncrasies, a certain directionality of possible mappings is observed across the languages. Figure 2 (a) shows that mapping from the tactile sense onto the others is commonly possible. Figure 2 (b) shows that the possibility of mapping from the gustatory sense to the tactile, visual, and auditory senses is low. Figure 2 (c) shows that the possibility of mapping from the olfactory sense to the tactile, visual (except Korean) and auditory senses is low. Figure 2 (d) shows that mapping from the auditory sense to the tactile, gustatory (except Japanese) and olfactory senses is likely to be very low across the languages. Figure 2 (e) shows that mapping from the visual sense to the tactile, gustatory and olfactory senses is very low, except for Dutch.

The target languages consist of both Indo-European and non-IE languages. Therefore, one cannot ascribe such universal patterns to the historical relationships of these languages. In this paper, we argue that synaesthesia should be explained in physiological terms. We will show that our accounts using the Physiological = Psychological model provide a systematic explanation of the universal patterns, as well as the idiosyncratic mappings as shown in the graphs.

2. The Physiological = Psychological Model

The Physiological = Psychological (PP) model is a cognitive model based on the findings of physiological and anatomical studies in brain science. In this model, psychological and cognitive phenomena are equated with physiological activities of the brain. It is due to this equation that the PP model argues that meanings are reactions in the brain against linguistic stimulus (e.g., linguistic sound or letter) and a process of language comprehension is a series of brain reactions.

Figure 3. Cognitive network in the PP model



The PP model designs types of cognitive domains and their interrelations according to the anatomical structure of the brain. The present version of the model assumes four major domains: the External Primary Domain, the Internal Primary Domain, the Internal Secondary Domain, and the External Secondary Domain. Each of these includes various sub-domains.[4] The process of comprehension is described as a variety of activities in these cognitive domains. Figure 3 is a sketch of the cognitive network in the PP model.

We describe the meaning of the word *fire*, for example, as in Figure 4. The figure shows the relationship between the meaning of *fire* and the bodily experience of fire. We experience fire in daily life and the brain learns what types of features are perceived with it. The experience of fire includes warmth, a burning smell, shape and colors of a flame, sound of sparks, etc. In our accounts, a set of reactions in the Tactile, Auditory, Visual, and Olfactory Senses take place through the Sensory Association.[5] The meaning of *fire* is a compound of various reactions in the brain.

Figure 4. Meaning of fire

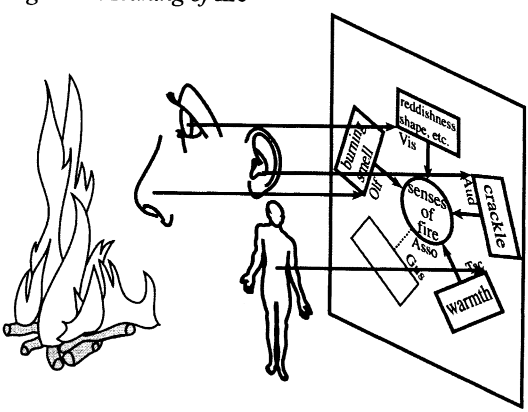


Figure 4 is not the description of the "process of comprehension" of *fire*. In the PP model, the process of linguistic comprehension is equated with a series of reactions in the various cognitive domains that are in associative relation with given linguistic stimulus. (1) is a schematic description of the reactions assumed to occur following the input of *fire*.[6]

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4 In this paper, due to the space, we limit our accounts of the structure of the PP model to a minimum. Interested readers are directed to Shibuya, Nozawa, and Kanamaru (in press) for a more detailed illustration of this new cognitive model.

5 Note that the first letter of each sense modality here is written in capitals. This is how we describe a process in the sub-domains in the PP model.

6 We distinguish the description of a process from the description of mental content. In the description of

(1) *Situation*:

Occurrence of the linguistic sounds of the word *fire*

Reactions in the hearer:

- Vibration of the eardrum (tympanum) [the linguistic sounds of *fire*]
- Reaction in the auditory nerve (inner ear nerve) [the linguistic sounds of *fire*]
- Reaction of the Auditory Sense [the linguistic sounds of *fire*]
- Reaction of the Sensory Association [the association between the auditory sense of the linguistic sounds of *fire* and the senses related to the elements of fire]
- A series of reactions in the sensory areas (caused through the reaction of the Sensory Association following the linguistic input of *fire*)

3. Constraint of Sensory Experiences

A particular sense tends to co-occur with other certain senses in daily life. In the case of experiencing warm objects, for instance, one learns the tactile sense of warmth and other sensory experiences such as the visual sense of reddishness of the objects as associated co-occurring senses. As illustrated above, the experience of fire includes the tactile sense of warmth as well as other senses such as the color of fire (reddishness), burning smell, etc. Likewise, the experience of electric stoves includes warmth and the colors of the heater (reddishness), as well as the shape and electric noises, etc.

Learning of simultaneous proximity between two senses enables the activation of one sense to cause the co-activation of the other sense. In the case of warm objects, the simultaneous proximity of the tactile sense of warmth and the visual sense of reddishness enables the activation of the former to cause the reaction of the latter. We argue that synaesthesia is processed through activation of co-occurring senses. (2) is a schematic description of how one processes *warm color*. The "mismatch" of sense modalities of tactility and vision is solved by the co-occurring associative relation between them, through a variety of reactions following the linguistic inputs of *warm* and *color*.

(2) *Situation*:

Occurrence of the linguistic sounds of *warm color*

Reactions in the hearer:

- Reaction of the Auditory Sense [the linguistic sounds of *warm*]
- Reaction of the Sensory Association [the association between the auditory sense of the linguistic sounds of *warm* and the tactile sense of warmth]
- Reaction of the Tactile Sense [warmth]

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question and [Y] as the "reaction corresponding to Y in X" (mental content).

- Priming in the Sensory Association [the association between the tactile sense of warmth and other senses that are in strong associative relation with warmth]
- Reaction of the Auditory Sense [the linguistic sounds of *color*]
- Reaction of the Sensory Association [the association between the auditory sense of the linguistic sounds of *color* and the visual sense of some colors]
- Reaction of the Visual Sense [reddishness]

We argue that comprehension of *warm color* is based on the sensory co-occurrence of different senses which one learns with warm objects. Experience of warm objects is of course not limited to speakers of English, but shared by speakers of other languages. In our accounts, the cross-linguistic availability of similar synaesthetic expressions stems from the similar bodily experiences one gets with an object and the physiological function of the brain that learns the sensory co-occurrence of different senses.

Sensory co-occurrence explains how one comprehends a given synaesthetic expression, but it does not account for the directionality of possible mappings. In order to explain such a problem, we need to discuss the functional differences of sense modalities.

Human beings have developed various types of sense modalities in the course of evolution. Each sense modality differs in its properties. For example, we can perceive an object through the olfactory, visual, and auditory senses without making any bodily contact, but the other senses such as the tactile and gustatory senses are different in this respect, since perception by these senses involves bodily contact with the object.

Having various types of senses with different functions is crucial for adaptive purposes, since it helps us to avoid risking our lives. For us, for example, the best way to examine the property of an unknown object is to use the visual or olfactory senses, because otherwise if the object turns out to be deadly poisonous, it is too late if we have touched or tasted it.

We argue that our adaptive behavior with the use of sense modalities fundamentally forms what we call the "structure of sensory experiences". At the fundamental level, functional differences in sense modalities affect the frequency of sensory co-occurrence (i.e., the strength of sensory association between different sense modalities), and frequency of sensory co-occurrence is responsible for the formation of such a structure.

In terms of the tactile and visual senses, for example, the structure of sensory experiences is that the sensory association from the tactile sense to the visual sense is stronger than that from the visual sense to the tactile sense. This is due to the frequency of sensory co-occurrence that takes place in bodily experiences. Use of the visual sense does not involve bodily contact, but that of the tactile sense is likely to involve the co-use of the visual sense. For example, touching a warm object normally also involves the visual information of the object, but looking at a warm object only provides the visual information.

Synaesthesia as discussed in this paper consists of a modifier and a modified element. In the semantic structure of synaesthesia, the modifier should evoke the sense which is in a strong associative relation with the sense evoked by the modified element. As mentioned, *warm color* and its equivalent expressions are cross-linguistically acceptable, whereas *red temperature* and its equivalent expressions are not. Given the arguments so far, it is clear that the former type forms more preferable sensory associative patterns than the latter. In the former, the modifier is in a strong associative relation with the visual sense of reddishness, whereas the latter evokes the sensory association from the visual sense to the tactile sense, which is anomalous in our sensory experiences. The structure of sensory experiences plays a crucial role in synaesthesia.

The same principle seems to be operating in other senses such as the gustatory and olfactory senses. In daily life, we are likely to use the olfactory sense instead of the gustatory sense as a means to make a prediction of the property of an object, since there is more risk in using the gustatory sense than the olfactory sense. When the gustatory sense is used, the olfactory sense has normally already been used. The sensory association from the gustatory to the olfactory sense should therefore be stronger than the other way around. As well as the case of the tactile and visual senses, the adaptive behavior with the use of the gustatory and olfactory senses forms the structure of sensory experiences.

Expressions such as *sweet taste* are cross-linguistically acceptable (e.g., *tian2de wei4dao4* [Chinese: 1], *zoete smaak* [Dutch: 1], *γλυκειά γεύση* [Greek: 1], *amai aji* [Japanese: 1], *dan mas* [Korean: 1]). On the other hand, the acceptability of expressions such as *smelly taste* is likely to be low (e.g., *chou4de wei4dao4* [Chinese: 1], *stinkende smaak* [Dutch: -1], *δύσοσμη γεύση* [Greek: -1], *kusai aji* [Japanese: 0], *gulihan mas* [Korean: 0]). The acceptability of the former is higher than the latter, because the gustatory experience evoked by the modifier is in a strong associative relation with an olfactory experience. The latter type evokes the sensory association from the olfactory sense to the gustatory sense which is anomalous in the structure of sensory experiences.

Williams' generalization suggests that mapping from the olfactory sense onto the gustatory sense should not take place. The anomaly of *smelly taste* seems to follow his generalization. We suggest, however, that his suggestion is not accurate enough, since there is indeed a case where such a mapping is possible (e.g., *fen1fang1de wei4dao4* [Chinese: 1], *zoete smaak* [Dutch: 1], *fragrant taste* [English: 0], *ευωδιαστή γεύση* [Greek: 0], *kaguwasii aji* [Japanese: 0], *hyanggiloun mas* [Korean: 0]). Williams' generalization does not explain the different acceptability between *smelly taste* and *fragrant taste*.

In our accounts, frequencies of sensory co-occurrence determine the acceptability of synaesthesia. Use of the gustatory sense depends on the type of smell. For example, when an object has a good smell, one is more likely to eat it than when the object has a bad smell. Eating fragrant food forms the strength of the sensory association between the senses evoked by *fragrant* and *taste*. The acceptability of *fragrant taste* and the equivalent expressions across the languages is motivated by the strength of sensory association. The anomaly of *smelly taste* and its equivalent expressions stems from the lack of sensory association. The association between *smelly* and *taste* is weak, since eating smelly food is usually not welcome by people.

The principle of the structure of sensory experiences seems more accurate than Williams' generalization. Adaptive behavior contributes to the formation of the structure of sensory experiences, and the structure of sensory experiences determines the semantic structure of synaesthesia. Physiological properties of sense modalities and adaptive behavior are not limited to speakers of a particular language, and hence a similar pattern of possible synaesthetic mappings is found across languages. Below is the semantic constraint of synaesthesia we propose as a constraint of sensory experiences.

Constraint of Sensory Co-occurrence:

In a synaesthetic expression consisting of a modifier and a modified element, the modifier should cause a sensory reaction which is in a strong associative relation with the sense caused by the modified element.

4. Constraint of Emotional Experiences

Synaesthesia also includes examples such as *sweet voice*, where mapping from the gustatory sense onto the auditory sense takes place. Equivalent expressions to *sweet voice* are also likely to be found acceptable across the languages in our sample (e.g., *tian2de sheng1yin1* [Chinese: 1], *zoete stem* [Dutch: 0], *γλυκειά φωνή* [Greek: 1], *amai koe* [Japanese: 1], *dan mogsoli* [Korean: -1]). According to Williams' generalization, such a mapping is predicted. In our accounts provided so far, however, examples such as *sweet voice* would be predicted as unacceptable against the fact, since sweetness and a voice are not likely to co-occur in daily life. This section introduces another type of constraint and discusses the advantages of our arguments in comparison to Williams' work.

In emotional processing, the amygdala (a subcortical region in the temporal lobe) in the limbic system plays the crucial role, and the reactions of the amygdala are caused by sensory stimuli (Gazzaniga et al. 1998). We argue that comprehension of *sweet voice* is made possible not by the constraint of sensory experiences, but by the constraint of emotional experiences. Sweetness in the gustatory sense would cause an emotion of pleasure. Likewise, a certain type of voice causes a similar type of emotion. Comprehension of *sweet voice* is achieved by the synthesis of the similar emotional value of pleasure evoked by the lexical elements. (3) is a schematic description of the process.

(3) *Situation*:

Occurrence of the linguistic sounds of *sweet voice*

Reactions in the hearer:

- Reaction of the Auditory Sense [the linguistic sounds of *sweet*]
- Reaction of the Sensory Association [the association between the auditory sense of the linguistic sounds of *sweet* and the gustatory sense of sweetness]
- Reaction of the Gustatory Sense [sweetness]
- Reaction of the Sensory Association (the association between the gustatory sense of sweetness and the emotion of pleasure)
- Reaction of Emotion [emotion of pleasure]
- Priming in the Sensory Association [the association between the emotion of pleasure and the senses that are in strong associative relation with such an emotion]
- Reaction of the Auditory Sense [the linguistic sounds of *voice*]
- Reaction of the Sensory Association [the association between the auditory sense of the linguistic sounds of *voice* and the auditory sense of some kind of voice]
- Reaction of the Auditory Sense [a voice that causes an emotion of pleasure]

We proposed the constraint of sensory experiences in the preceding section. Synaesthesia involves two different types of constraints. The constraint of emotional experiences can be formalized as follows:

Constraint of Emotional Similarity:

In a synaesthetic expression consisting of a modifier and a modified element, the modifier should evoke an emotion which matches with the emotion evoked by the modified element.

There are some advantages to propose such a constraint. Firstly, in comparison with Williams' generalization, the Emotional Similarity constraint explains cases which cannot be captured by his generalization. For example, *bitter pain* and *sweet touch* conform to mapping from the gustatory onto the tactile sense, but such a fact cannot be captured by Williams' generalization. In our accounts, the acceptability of *bitter pain* is explained by the synthesis of the emotion of agony evoked by the lexical elements of this expression. Likewise, the acceptability of *sweet touch* is explained by the synthesis of the emotional value of pleasure evoked by *sweet* and *touch.*

Secondly, the constraint explains cases which are not assumed by Williams' generalization. For example, mapping from the olfactory onto the auditory sense is not assumed by Williams' generalization, but there are in fact instances such as *fragrant music*, which conforms to such a mapping. In our account, comprehension of *fragrant music* is made possible by the synthesis of pleasant feeling evoked by the lexical elements. In daily life, fragrance and sound are not likely to co-occur. It is not the Sensory Co-occurrence constraint, but the Emotional Similarity constraint that makes such a mapping possible.

Thirdly, the constraint is consistent with anatomical structures of the brain. The amygdala is interconnected with various structures in the limbic system, and one of these includes the hypothalamus (an output system for the amygdala) (Rolls 1999). An interesting fact about the hypothalamus is that hypothalamic neurons in the lateral hypothalamus are responsive to the sight, smell, and taste of food (Rolls 1999: 19). According to the results of our survey, a number of examples that violate Williams' generalization relate to the visual, olfactory, and gustatory senses (see Figure 2). In our accounts, such linguistic facts and the empirical findings of the brain can also be captured in relation to emotion.

Moreover, in relation to the above discussion, the constraint also captures subtle aspects of synaesthesia. An emotional value caused by sensory stimulus should differ among individuals or in cultures. Figure 2 (d), for example, shows that Japanese shows a peculiarity to other languages in terms of the mapping from the auditory sense to the gustatory sense. In Japanese, for example, *urusai aji* is judged acceptable if given a context, but its equivalent expressions in other languages are likely to be judged anomalous (e.g., *chao3za2de wei4dao4* [Chinese: -1], *luide smaak* [Dutch: -1], *loud taste* [English: -1], *δυνατή γεύση* [Greek: 1], *solanseuleoun mas* [Korean: -1]). In our accounts, such differences are explained by the availability of emotional matching.

Last but not least, the constraint makes it clear what kind of principle causes a mapping to be possible. In section 3, we mentioned that Williams' generalization does not tell us the cause of the different acceptability between *smelly taste* and *fragrant taste*. A similar ambiguity can be found in instances such as *sweet voice*. As mentioned, his generalization predicts *sweet voice* to be possible, but it is again not clear why it is so. In our accounts, it is the Emotional Similarity constraint that makes such a mapping possible.

5. Conclusion

This paper introduced a cognitive model called the PP model and discussed constraints of synaesthesia across a variety of languages. Two types of constraints were proposed. Regarding the constraint of sensory experiences, we discussed the importance of what we call the structure of sensory experiences. Regarding the constraint of emotional experiences, we mentioned the role played by emotion. We showed that Williams' generalization suffers from several problems. By using the PP model, we presented a systematic analysis of synaesthesia which is compatible with the structure of the brain.

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