

# Research on Color Attention Bias Caused by Olfactory Stimulation in Visual Search Task

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**Abstract.** People often connect and integrate information from different sensory channels to form cross-channel connection. Previous studies have proved that vision, as a dominant perception, will affect the perception and recognition of olfactory channels. This study attempts to prove experimentally that olfactory channels have an influence on the perception and recognition of visual information. Experimental method: Subjects were asked to search the target with a specific shape visually after deeply smelling fragrance card, and their respective reaction time was tested. The indicative of olfactory stimuli is regarded as an intragroup variable, and the forward and reverse correlation between target color and olfactory stimuli is regarded as an inter-group variable. The experimental results show that when the color associated with olfactory stimulation appears on the target pattern, it will speed up the visual search, but when the color associated with olfactory stimulation appears on the interference pattern, it will hinder the visual search speed. Conclusion: It is proved that olfactory cues will lead to visual attention bias to its associated colors, indicating that there is a cross-channel influence of olfactory stimuli on visual attention.

**Keywords:** visual olfactory synesthesia; cross-channel connection; attention bias.

## 1. Introduction

We live in a world that provides multi-sensory channel stimulation. We not only integrate information from multiple senses, but also tend to connect different sensory channel information to form cross-channel connection (Spence, 2011). For example, people's experience in flavor stems from the multi-sensory integration of related sensory information in food and drink, such as taste, smell, texture and so on. However, our inherent cognitive, situational and learning factors may affect the perception and interpretation of sensory information (Lee, 2006). Individuals will expect the flavor of food and beverage after seeing its color (Shankar ,2009), which shows the cross-channel influence of color on flavor perception.

### 1.1. background of the selected topic

There is relatively little research on the influence of olfactory channels on visual processing. Previous studies have shown that the information of visual channels will affect people's expectation, perception and judgment of flavor (Spence, 2011). People often rely on the color clues presented by visual channels to identify and judge the flavor of food, beverage and fragrant articles, but when the color and flavor do not conform to the individual's own inherent color-smell synesthesia, it is difficult for individuals to identify the correct flavor (Wen, 2009). However, few studies have investigated the regulation of flavor on color information processing. On the one hand, visual channel is dominant as the dominant channel of perception (Koppen & Spence, 2007), which makes color information easily affect people's processing of flavor information, but olfactory information is difficult to affect color information processing. On the other hand, the presentation and manipulation of smell is not very easy to realize, which makes it difficult to explore the influence of olfactory information on visual information processing.

The research on the influence path of other sensory channels on visual processing provides enlightenment for exploring the influence of olfactory channels on visual search. Relevant research shows that the promotion of traditional sensory channels to visual search is realized in a bottom-up



path. For example, auditory information promotes visual search because individuals integrate visual cues presented synchronously in time with the target in visual search, increasing the salience of the target so that the target can "jump out" from the interference items. Regardless of the same pathway or not, the information of other sensory channels can arouse individuals' selective attention to certain stimuli (Weierich, 2008). Therefore, it is speculated that the color-smell connection of the subjects themselves may also lead to the attention bias of the flavor clues to the colors associated with them. The influence path of olfactory channel is from top to bottom, that is to say, when individuals receive the stimulus information of olfactory channel, they will expect the task target, and the effect of promoting visual search can be achieved through the color redundancy gain provided by this expectation.

Previous studies have shown that individuals can predict the color of the target object based on its flavor label, which in turn affects visual search. For example, in daily life, people often see food, drinks, perfume, etc. through visual processing first, and then smell or taste processing to get the real experience of flavor. Moreover, the color will be noticed first in many visual clues, so people often get the color information of the target product first, and then try to get intuitive and true flavor information through taste and smell. However, for packaged food, beverage and fragrance products, flavor labels are often printed on the outer packaging, so it is also possible for individuals to obtain flavor information through flavor labels before actual experience. For instance, psychologists have investigated the influence of flavor labels on color expectation through experiments. When searching for the taste of potato chips, the subjects will first predict the color of the packaging through the flavor-color connection formed in daily life, and give priority to using the color to search for the taste of potato chips. However, when the flavor and color matching of the search target does not conform to the inherent packaging flavor-color association of the subjects, it goes against the color expectation of the subjects. At this point, the subjects cannot find it through color search, so they need to turn back to text search, resulting in a slower visual search response (Huang, 2019, 2021). However, flavor tags are provided by visual channels, so it is still unknown what cross-channel impact the actual flavor information will have on individual visual search.

The research on human perception mainly focuses on the fields of vision and hearing. Nonetheless, the sense of smell is the oldest sensory function in the history of biological evolution. This function is not only very important for foraging, communication among individuals and emotional activities, but also affects the development of individuals and species. As an important sensory channel, the olfactory channel will inevitably affect the integration of people's perception.

Starting with the practical application direction of sensory channel integration research, this paper explores the possible role of olfactory channel in practical application and the directions worthy of study. First of all, this study explores the important practical significance of multi-sensory channel combination. By using CiteSpace software, the top 400 cited articles in CNKI with "multi-sensory channel" as the key word are measured and clustered, and it can be concluded that the research on multi-sensory channel combination in recent years mainly serves the development and application of virtual reality technology, interactive design and packaging design, as shown in Figure 1. Secondly, this study explores the possible role of olfactory channels. Studies have shown that the olfactory system and emotional system are highly overlapped in neuroanatomy, which means that people's reactions to smells are naturally emotional. On the conscious and subconscious levels, smell can regulate our physiological response, emotional experience and external behavior through a series of olfactory processing processes (Zhou, 2012). The characteristics of the smell itself and the emotionality of the olfactory channel are the effective means of practical application. Finally, based on the characteristics of olfactory information and olfactory channels and cross-modal coherence, the practical application is extended and developed. For example, in packaging design, there is a way to directly use smell: extract the smell of the product and blend it into the adhesive, paint and material of the packaging. When consumers get close, they can feel the overall atmosphere of the packaging and stimulate the desire for consumption (Zhou, 2017). Among the virtual technology and reality

enhancement technology, the sense of smell provides a wider range of sensory information and is more immersive.

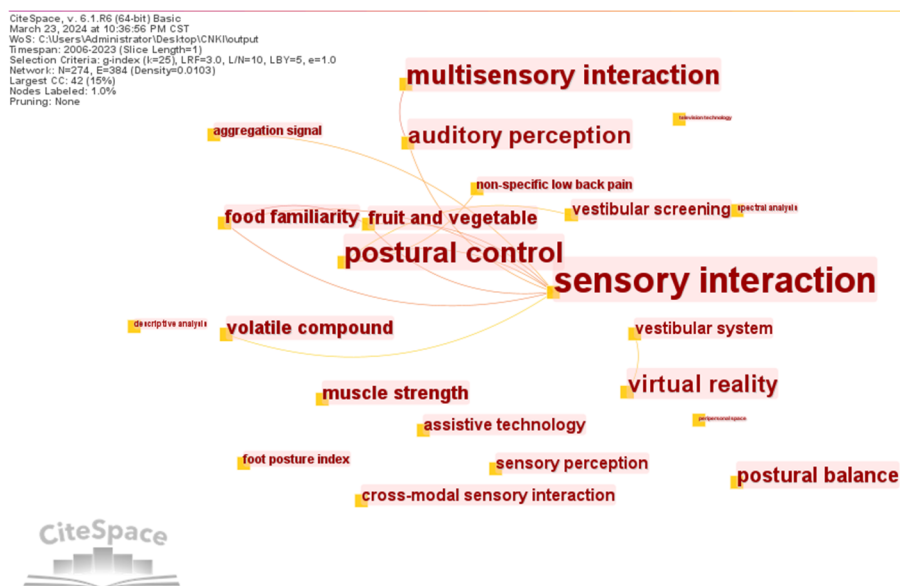


Figure 1. Research hotspot cluster diagram

## 1.2. Tasks of the experiment

In this study, the behavioral experiment of visual search reaction was carried out, focusing on the possible influence of flavor information on visual search, and also on revealing the visual attention bias caused by olfactory cues. The specific research content is the attention bias of specific olfactory stimuli to their associated colors.

The experimental task requires the subjects to smell fragrance card first and then search the target with a specific shape visually, and the smell of the fragrance card will prompt the color of the target. Before the experiment officially begins, the experimenter will tell the subjects what color the fragrance card smell corresponds to, and the correlation between each smell and the color of the target in the subsequent visual search. Among them, the presentation of different olfactory stimuli is realized by the replacement of fragrance cards. The experiment adopts the visual search paradigm proposed by Moriya in 2018. The specific task is to find the target with specific shape characteristics in two visual stimuli with different colors and make a behavioral response to the shape characteristics. By manipulating the forward and reverse correlation of olfactory stimuli to the target, the experiment investigates the influence of real olfactory stimuli on subsequent visual search tasks.

## 1.3. Research hypotheses

Although the task of visual search is to find a target with a certain shape, predicting the color of the target can speed up the visual search by providing redundant gain (Grubert, 2011). However, when the color associated with olfactory stimulation appears on the interference item, the subjects pay attention to the interference item first under the influence of the expected color, which increases the time for them to pay attention to the correct target pattern and make a choice according to its specific shape.

Therefore, the research hypotheses are put forward. H1: individuals can predict the target color through indicative olfactory stimulation and promote the visual search for shape targets, which shows that their visual search speed is accelerated. H2: When the smell-related color appears on the screen as an interference item, the smell clue will cause the individual to pay attention to the color of the interference item, so it will hinder the visual search task to some extent, which shows that its visual search speed is slow.

## 2. Experiment Design

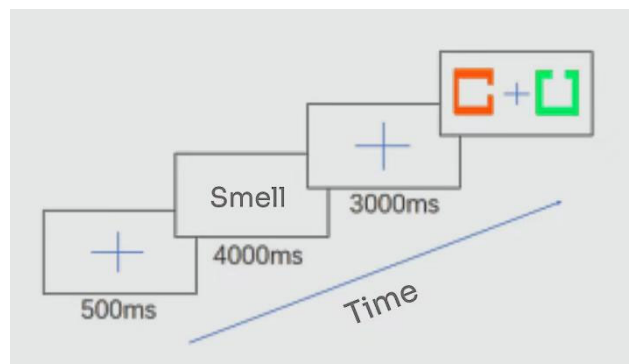
### 2.1. Subjects

Considering the possible problems in the experiment (such as subjects quitting the experiment, invalid data, or experimental apparatus failure), 40 subjects were recruited in the experiment, aged between 19 and 22, with an average age of 20.425, including 24 females and 16 males. All the subjects in this study are students of Southwest Minzu University. Every subject signed an informed consent form before taking part in the experiment. After completing the experiment, they were paid according to the standard of 15 yuan for each experiment. All subjects were right-handed, with normal vision acuity or corrected vision acuity, no color blindness or color weakness, and other senses, for example, smell, are also normal.

### 2.2. Apparatus and materials for experiment

In this experiment, perfume with rose flavor and pineapple flavor was used to present the smell stimulation, and tasteless pure fragrance cards were used as the control group. These two olfactory-stimulating perfumes are presented by pressing a pump on pure fragrance card in each experiment. In the pre-experiment, 10 other subjects were asked to deeply smell and identify the three fragrance card, and it was found that they could correctly tell what the smell of each fragrance card was without any other clues, and they all said that they were familiar with both smells.

The visual search task is carried out on the computer. E-prime software is used to write programs and record data, and visual stimuli are presented on a computer monitor with a screen resolution of 1024×768 and a refresh frequency of 85 Hz. The visual search task used in the experiment is similar to that proposed by Moriya in 2018. As shown in Figure 2, the center of the visual search screen will present a cross gaze point. A square frame with a gap is presented at the left and right positions of the gaze point. The gap of the target pattern is above or below the frame, and the gap of the interference item pattern is on the left or right. Each picture includes a target and an interference item. The colors of targets and interference items are always different in each picture. The olfactory stimulus of rose flavor used in this experiment is associated with color red, and the olfactory stimulus of pineapple flavor is associated with color red. The colors of interference items may be four commonly seen colors: red, yellow, green or blue.



**Figure 2.** Presentation order of stimuli in a single experiment.

### 2.3. Experiment process

In this experiment, a mixed design of 2 (olfactory stimulus indicative: providing color clue or not) × 2 (correlation between target color and smell: forward correlation or reverse correlation) was adopted, in which olfactory stimulus indicative was an intra-group variable and the correlation between target color and smell was an inter-group variable. The dependent variables are the response time and accuracy of the search shape target.

In the preparation stage of the experiment, the subjects will first read the instructions to understand the basic instructions and operation methods of the experiment, that is, tell the subjects that they are

going to smell three types of fragrance cards in the experiment. The olfactory stimuli of rose flavor and pineapple flavor are indicative of the target color in the subsequent visual search, while the "odorless" olfactory stimuli are not indicative of the target color. Then, continue to provide exercise experiment for three times to ensure that participants are familiar with the experimental process. After the exercise experiment, enter the formal experiment. Each experiment includes the following steps: ① fixation point presentation: firstly, a fixation point with a "+" sign lasting for 500 milliseconds (ms) is presented; (2) olfactory stimulation: then, participants need to smell the fragrance card for 4000ms; ③ the fixation point reappears: then the fixation point reappears for 3000ms; ④ the detection interface: at last, the detection interface appears, requiring participants to respond. Participants are required to judge the opening direction of the target. For the target with upward opening, press the "Z" key on the keyboard, and for the target with downward opening, press the "M" key.

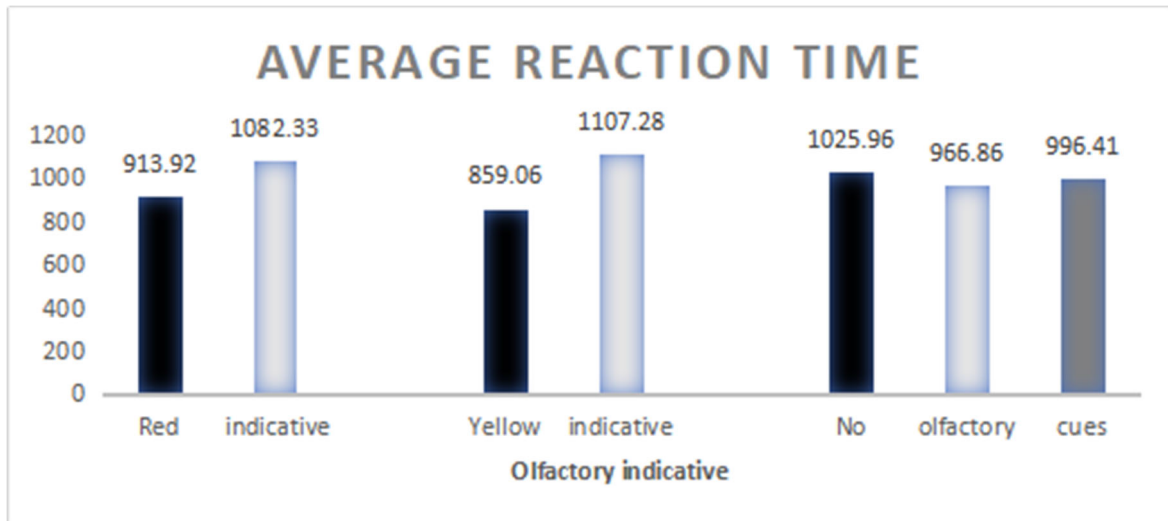
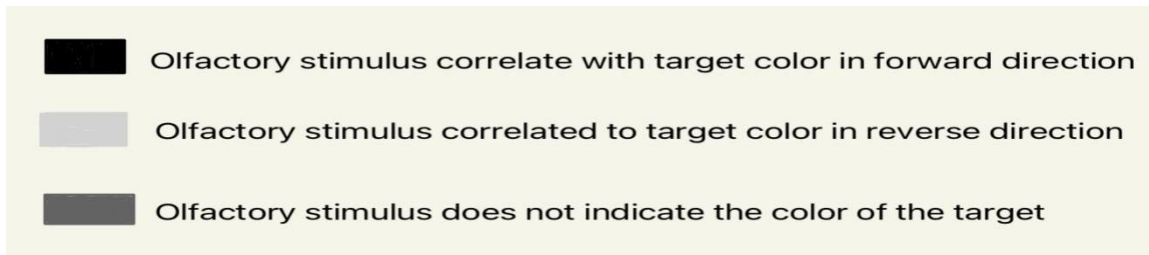
The detection interface consists of a central cross gaze point (+) and two left and right square boxes with half sides hollowed out. The direction of the truncated edge is called "opening direction". One box is used as the "target" and the other as the interference item. The colors of targets and interference items may be red, yellow, blue or green.

The subjects were randomly divided into two groups, one group did the forward correlation experiment and the other group did the reverse correlation experiment. In the experiment of forward correlation, the subjects were told that if they smell fragrance card A (rose flavor), it means that a red target will appear in the next visual search, and if they smell fragrance card B (pineapple flavor), it means that the next target is yellow, which means the color of the target suggested by the olfactory cue is forwardly correlated with the indicative of the olfactory stimulus. Another group of subjects were told that if they smell fragrance card A (rose flavor), it means that red interference items will appear in the next visual search, and if they smell fragrance card B (pineapple flavor), it means that the next interference item is yellow, that is, the color of the target suggested by the olfactory cue is inversely related to the indicative of the olfactory stimulus. In half of the trials, the olfactory stimuli (rose flavor and pineapple flavor) indicated the target color, while in the other half, the olfactory stimuli (pure Shankar) did not indicate the target color, so the trials with rose flavor, pineapple flavor and pure odorless accounted for 1/4, 1/4 and 1/2 respectively, and each participant completed 96 trials.

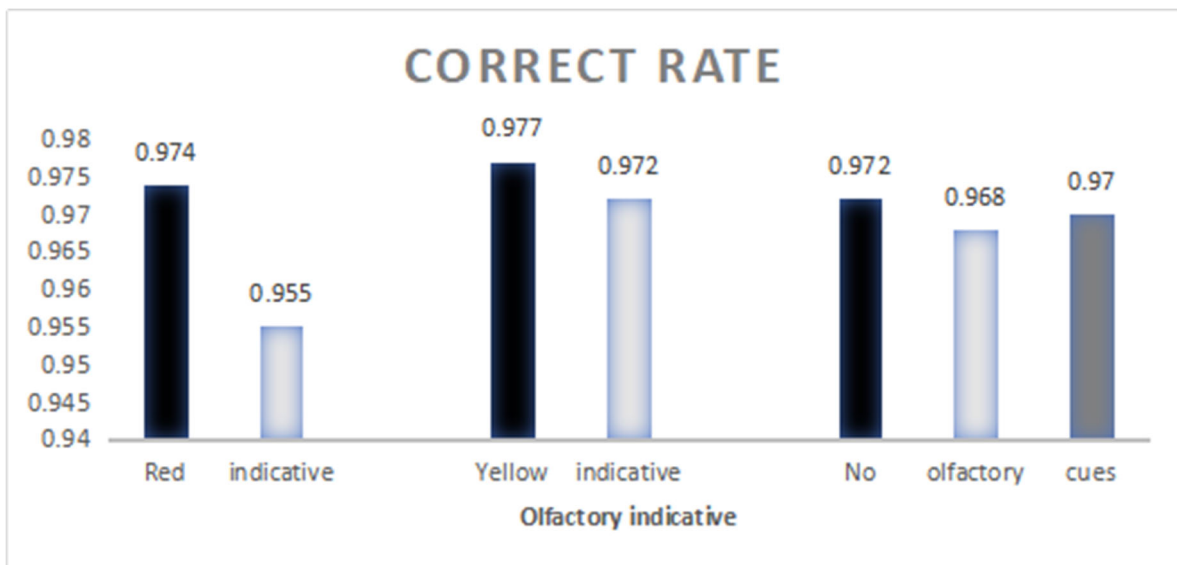
This experiment adopts chunk design, which includes four big chunks, and the subjects can decide whether to rest or not between each chunk. Each chunk includes 24 trials, and the olfactory stimuli in these 24 trials are the same. It starts with pure odorless fragrance cards chunks, followed by rose fragrant cards, then pure odorless fragrance cards, and finally pineapple fragrance cards. After each block with indicative fragrance cards, a block with pure odorless fragrance cards will be followed to control the possible error caused by odor dispersion. The colors of the target and the interference items in each trial are different, and the left and right positions of the target are controlled to be balanced.

### **3. Experimental Results**

The correct rate of subjects in this experiment is high, reaching 97.04%. In the data analysis, the trial data beyond 3 standard deviations of the average response time of the group were not included in the analysis, so 53 experimental data were excluded, accounting for 1.5% of the total data. According to the correct reaction, the average reaction time and accuracy are calculated, as shown in Figures 3 and 4.

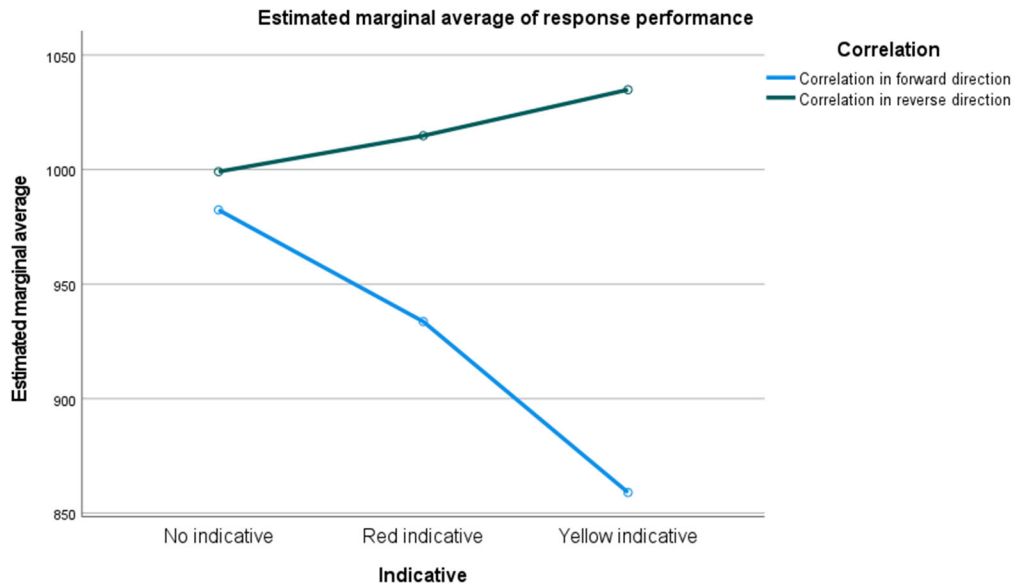


**Figure 3.** Reaction time of visual search when olfactory stimulus is forwardly or reversely related to target color



**Figure 4.** Correct rate of visual search when olfactory stimulus is forwardly or reversely related to target color

The mixed variance analysis of these data shows that the main effect of the correlation between olfactory stimulation and target color is significant in response time, and the visual search of subjects is significantly faster when olfactory stimulation is forwardly correlated with target color than when it is reversely correlated with target prompt (886.49 ms vs 1094.81 ms),  $F = 34.476$ ,  $p < 0.001$ . In addition, as shown in Figure 5, significant interaction was found in the reaction,  $F = 9.771$ ,  $p < 0.001$ . Other main effects or interactions are not significant in reaction time or accuracy data.



**Figure 5.** Outline of experimental interaction effect

In order to explain the interaction in reaction time, a simple effect analysis was carried out. When the color of the target is forwardly correlated with the indicative of the olfactory stimulus, the main effect of the indicative of the olfactory stimulus is significant in response time, and the visual search is significantly faster when the olfactory stimulus prompts the color of the target than when it does not (886.49 ms vs 996.41ms),  $F = 11.780$ ,  $p < 0.001$ . When the target color is inversely related to olfactory stimuli, the main effect of olfactory stimuli is not significant in reaction time,  $F = 0.989$ ,  $p = 0.372$ .

The analysis of variance of single-factor repeated measurement shows that pure odorless fragrance cards, rose fragrant cards and pineapple fragrance cards are equivalent to three levels of olfactory cue. In the forward correlation experiment, the main effect of olfactory cue is significant in reaction time, with  $F = 10.944$  and  $p < 0.001$  not significant in accuracy. Paired comparison shows that when the olfactory stimulus prompts the target color, the search speed of the subjects is significantly faster than that when the olfactory stimulus does not prompt the target color (886.49 ms vs 1025.96 ms). In the reverse correlation experiment, the main effect of olfactory cue is significant in reaction time,  $F = 8.597$ , assuming sphericity  $p < 0.001$ , not significant in accuracy. Paired comparison shows that when the olfactory stimulus prompts the color of the interference item, the search speed of the target is significantly slower than that when the olfactory stimulus does not prompt the color of the interference item (1094.81 ms vs 966.86 ms).

## 4. Discussion

### 4.1. Conclusions of the experiment

This experiment draws two main conclusions.

(1) In the experiment, the visual search of the target is faster when the olfactory stimulus prompts the color of the target than when it does not. It is proved that the subjects can predict the color of the target through indicative olfactory stimulation, which provides redundant gain for completing the visual search task of the shape target (Grubert, 2011) and speeds up the search, which is consistent with H1 of this experiment. This result is consistent with the previous research that presenting flavor information through text labels of visual channels can promote subsequent visual search (Huang, 2019). However, because the flavor information in this experiment is presented through the olfactory stimulation of the olfactory channel, this result shows that individuals can expect the color of the target in visual search according to the truly experienced olfactory information.

(2) In the experiment, the visual search of the shape target is slower when the target color is inversely related to the olfactory indicative than when it is not. The experimental results show that if the color

of the interference item is the color of the olfactory stimulus cue, that is, the target color is inversely related to the olfactory indicative, the speed of the participants to complete the visual search task of the shape target will be slow. This result shows that olfactory cues can trigger people's attention bias to related colors. In the experiment, the subjects will give priority to the interference pattern that matches the indicative color, thus prolonging the time to make the correct response, which is consistent with H2 in this experiment. It is also consistent with the conclusion that the intrinsic representation of this activation can make the subjects pay attention to the items with this representation (Moriya, 2018).

#### **4.2. Psychological mechanism**

In the past, the research results on the internal path of information from non-visual sensory channels affecting visual search were controversial. For example, whether auditory information promotes visual search is due to bottom-up guidance (van der Burg, 2008) or top-down guidance (Orchard-Mills, 2013). The experimental results about the influence of olfactory stimuli on visual search are basically consistent with the findings of Orchard-Mills (2013), which means the cross-channel influence will be influenced by the subjective prediction of the visual characteristics of the target. Therefore, this cross-channel influence on visual search is mainly due to top-down attention guidance.

The reason why the research results confirm this statement is that the olfactory information in this experiment is not presented synchronously with the visual information, but before the visual information. Furthermore, the task of the subjects was originally to search for a target with specific shape characteristics, and the color characteristics of the target were not related to the task. In a trial cycle, there are four steps, namely, to concentrate the attention of the subjects (cross gaze point), to obtain olfactory information (smell taste), to identify the body and make expectations (cross gaze point), and to complete the visual task selection (target shape selection). In an experimental trial cycle, subjects will not only get olfactory clues in advance, but also have time to expect visual search tasks. Both the forward and reverse correlation experiments between the target color and the olfactory cue show that this indicative olfactory information will lead to the attention bias of the associated color of the subjects.

#### **4.3. Research contribution**

This study investigates the influence of real olfactory cues on visual search, and reveals the visual attention bias of related colors caused by the information provided by smell. The innovative contribution of this study is to study the stimulus information provided to the subjects through the real olfactory channel, while excluding the influence of visual channel information. The results show that although the dominance of visual channels makes it easier for people to process flavor information (Stäger, 2021), olfactory channel information can also regulate people's processing of color information in specific task situations.

This study investigates the influence of real olfactory cues on visual search, and reveals that smelling a specific smell will lead to visual attention bias to related colors. In the research, it makes up for the lack of experimental research evidence on the influence of olfactory channel in color-olfactory synesthesia, and explores the internal mechanism of the mutual integration and influence of vision and smell, which has certain enlightening significance for people to understand other types of cross-channel influence. In practice, it can be popularized by using experimental conclusions. For example: the promotion of virtual reality technology. It can also promote the development of modern lifestyle and further improve virtual reality technology, for instance, adding olfactory channel stimulation to AR technology to enhance the sense of reality; and the promotion of interaction design. Moreover, it provides more possibilities for the realization of interactive design, such as helping marketing practitioners to understand the visual attention characteristics of consumers in the environment related to smell and apply them to the marketing activities of products, brands or stores, and helping product packaging practitioners to design visual packaging materials according to the smell characteristics of products.

#### 4.4. Research limitations

Certainly, this study also has some limitations. First of all, the olfactory indicative stimulus in the color-smell connection investigated in this study is often associated with a specific object. Even if the subject was not told what perfume he/she smelt, the subject might still have semantic activation after identifying the indicative olfactory stimulus. In the future, the experiment results can be verified by using novel olfactory stimuli that are difficult for subjects to connect with specific objects. Secondly, this experiment adopts chunk design, mainly considering that random design is not convenient to replace fragrance cards, and there may be odor dispersion between different olfactory stimuli, which may interfere with the experiment and cause errors. However, the effect of chunk design is not as robust as that of random design, so the future research can consider improving the olfactory stimulation instrument to prevent the subjects from being disturbed by diffuse odor. Thirdly, there are many trails of experiments in this study, which may have certain practice effect. Moreover, after the interview, when they know that olfactory stimulation does not prompt the color of the target, but the color of the interference item, the subjects tend to ignore the olfactory information and the color information presented by the pattern, and only make a choice and judgment on the two shapes and patterns with different openings.

#### 5. Conclusion

The experiment results of this study show that the visual search speed can be accelerated when the color prompted by olfactory stimulation appears on the target of visual search task. However, if the color associated with the olfactory stimulus appears on the interference item, the olfactory stimulus will hinder the visual search. It reveals that the experience of real olfactory information will lead to the visual attention bias of related colors, which is a top-down psychological realization path and clearly shows the influence of olfactory channels on visual search.

#### References

- [1] Grubert, A., Krummenacher, J., & Eimer, M. (2011). Redundancy gains in pop-out visual search are determined by top-down task set: Behavioral and electrophysiological evidence. *Journal of Vision*, 11(14), 10.
- [2] Huang, J., Wang, F., Sui, J., & Wan, X. (2019). Functional and structural basis of the color-flavor incongruency effect in visual search. *Neuropsychologia*, 127, 66–74.
- [3] Huang, F., Wang, C., & Wan, X. (2022). Color-flavor interactions in associative learning: Evidence from a computerized matching task. *Food Quality and Preference*, 95, 104364.
- [4] Koppen, C., & Spence, C. (2007). Seeing the light: Exploring the Colavita visual dominance effect. *Experimental Brain Research*, 180, 737–754.
- [5] Lee, L., Shane, F., & Ariely, D. (2006). Research article: Try it, you'll like it: The influence of expectation, consumption, and revelation on preferences for beer. *Psychological Science*, 17(12), 1054–1058.
- [6] Moriya, J. (2018). Visual mental imagery influences attentional guidance in a visual-search task. *Attention, Perception, & Psychophysics*, 80(5), 1127–1142.
- [7] Orchard-Mills, E., Alais, D., & van der Burg, E. (2013). Crossmodal associations between vision, touch, and audition influence visual search through top-down attention, not bottom-up capture. *Attention, Perception, & Psychophysics*, 75(8), 1892–1905.
- [8] Shankar, M. U., Levitan, C. A., Prescott, J., & Spence, C. (2009). The influence of color and label information on flavor perception. *Chemosensory Perception*, 2(2), 53–58.
- [9] Spence, C. (2011). Crossmodal correspondences: A tutorial review. *Attention, Perception and Psychophysics*, 73(4), 971–995.
- [10] Spence, C. (2019). On the relationship (s) between color and taste/flavor. *Experimental Psychology*, 66(2), 99–111.
- [11] Spence, C., Parise, C., & Chen, Y. C. (2012). The Colavita visual dominance effect. In: M. M, Murray & M. T. Wallace (Eds.), *The neural bases of multisensory processes* (pp. 529–556). Boca Raton (FL): CRC Press
- [12] Stäger, L., Roel Lesur, M., & Lenggenhager, B. (2021). What am I drinking? Vision modulates the perceived flavor of drinks, but no evidence of flavor altering color perception in a mixed reality paradigm. *Frontiers in Psychology*, 12, 641069

- [13] van der Burg, E., Olivers, C. N. L., Bronkhorst, A. W., & Theeuwes, J. (2008). Pip and pop: Nonspatial auditory signals improve spatial visual search. *Journal of Experimental Psychology: Human Perception and Performance*, 34, 1053–1065.
- [14] Weierich, M. R., Treat, T. A., & Hollingworth, A. (2008). Theories and measurement of visual attentional processing in anxiety. *Cognition & Emotion*, 22, 985–1018.
- [15] Wen, X.H., Liu, Q., Sun, H.J., Zhang, Q.L., Yin, Q.Q., Hao, M.J., & Mou, H.R. (2009). Theoretical model of multi-sensory cue integration. *Advances in Psychological Science* (04),659-666.
- [16] Zhou, W. & Feng, G. (2012). Olfactory perception and its interaction with emotional system. *Advances in Psychological Science*, 20(1), 2-9.
- [17] Zhou, Y. & Zhang, R.Y. (2017). Application of Multi-sensory Integration Concept in Food Packaging Design. *Industrial Design*, 1