Developing and validating a multi-dimensional scale for freshness perception of home air-care products

by

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B.S., Shanghai Institute of Technology, 2013
M.S., Kansas State University, 2020
M.S., Kansas State University, 2023

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Food, Nutrition, Dietetics and Health
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Abstract

Freshness is a complex concept that encompasses both physiological and psychological dimensions. The goal of this dissertation is to develop and validate a standardized scale that measures consumer perceptions of freshness in home fragrances comprehensively, addressing a major gap in understanding freshness perception across different contexts and products.

In the first phase, a qualitative approach was used to explore consumer terminology that contributes to freshness perception of home fragrances. Focus groups and E-commerce comment reviews helped identify key dimensions of freshness, including emotional and psychological factors, environmental elements, physical sensations, product context, and functional roles. These findings provide an understanding of how freshness is experienced by consumers, emphasizing aspects such as comfort, air quality, and lightness of scent.

In the second phase, the scale was refined through a national survey. Factor analysis was used to ensure reliability and validity. Results confirmed four key dimensions of freshness perception such as environmental functionality, personal productivity, contextual associations, and emotional nostalgia. These dimensions had high internal consistency indicated by Cronbach's alpha and highlight the importance of emotional, sensory, and environmental attributes in shaping consumers' understanding of freshness in home fragrances.

In the third phase, the validated freshness scale was used in the context of product usage to determine its effectiveness in capturing consumer perceptions of home fragrances. The effectiveness of the freshness scale was further demonstrated. The findings showed that freshness involves more than just a pleasant fragrance; it also contributes to creating a cleaner, more comfortable environment. A Linen Clean scent, which enhances cleanliness and comfort perception, was rated as the most "fresh". The results suggest that product development may

focus on both sensory and environmental aspects to better meet consumer needs and expectations.

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Chapter 1 - Literature Review

Understanding Freshness Perception

Freshness is a fundamental attribute that significantly influences consumer perception and satisfaction across various consumer goods, both in the food and non-food industry. It is conventionally defined as the state of maintaining original qualities unimpaired or being renewed in energy, as per the Merriam-Webster dictionary. Historically, freshness has played a crucial role in how people consume and perceive products, especially when preservation methods were limited. This broad concept encompasses both physiological and psychological dimensions, affecting perceptions of quality, safety, health, and desirability Ozdogan et al. (2021); Yu et al. (2021).

In the current market, consumers are increasingly conscious of sensory attributes, favoring products that deliver freshness, quality, and overall satisfaction. There is also a growing preference for natural, minimally processed goods, which has driven industries to prioritize freshness in product development and marketing. Understanding and enhancing the sensory attributes linked to freshness has become critical for meeting consumer expectations and maintaining market competitiveness (Petrescu et al., 2020; Rahman et al., 2021; Yu et al., 2021.

The perception of freshness is a complex interplay between physiological responses and psychological factors. Sensory assessment involves evaluating visual, tactile, and olfactory cues that contribute to the overall product experience (Lawless and Heymann, 2010). Attributes such as color, gloss, and texture immediately impact consumer perception. Texture, perceived through both touch and mouthfeel, affects the assessment of freshness with qualities such as hardness, softness, and juiciness playing key roles. Flavor, which integrates taste and smell, is also essential for freshness perception. The olfactory system detects aromatic compounds, triggering responses in the brain's sensory and emotional processing regions (Ozdogan et al., 2021; Sowndhararajan and Kim, 2016; Strous and Shoenfeld, 2006). Positive sensory experiences with pleasant flavors can enhance mood and promote a sense of well-being, while negative cues can lead to adverse reactions and reduced consumer acceptance (Barsyte et al., 2023).

The perception of freshness is not only influenced by sensory processes but also involves cognitive and emotional components that shape individual experiences and preferences. By understanding the mechanisms behind freshness perception, industries can enhance product appeal and meet consumer expectations more effectively (Petrescu et al. 2020; Rahman et al. 2021).

Freshness Perception from Physiological and Psychological Perspectives

Physiological aspects in freshness perception

The perception of freshness begins with the human sensory systems and neural pathways that process environmental stimuli. Mammalian sensory systems utilize two types of neuronal maps to organize and process sensory information: continuous and discrete (Francia and Lodovichi, 2021). Continuous maps preserve the spatial relationships of stimuli, where adjacent neurons in the periphery project to neighboring neurons in the brain, maintaining a spatial pattern. This is typical for sensory modalities such as vision, where the arrangement of photoreceptors in the retina reflects in the brain's visual processing regions (Barwich, 2020). In contrast, discrete maps organize sensory inputs based on specific features rather than spatial order. In the olfactory system, sensory neurons expressing the same odorant receptor converge at distinct locations in the olfactory bulb, forming glomeruli. This results in a map where the identity of the odorant receptor dictates the organization, allowing the processing of odor information independently of spatial distribution (Barwich, 2020).

G-protein-coupled receptors (GPCRs) are important membrane proteins that convert external signals—such as hormones, neurotransmitters, and sensory stimuli—into specific cellular responses (Billesbølle et al., 2023). These receptors are integral to sensory perception, playing key roles in vision, taste, and smell. In vision, GPCRs such as rhodopsin respond to light by triggering a signaling cascade that allows the brain to perceive visual information (McGann, 2017). In olfaction, a diverse family of GPCRs detects different odor molecules, translating chemical signals into the perception of smell (Barwich, 2020). Similarly, in taste, GPCRs are involved in recognizing sweet, bitter, and umami flavors, contributing to the overall sensory experience of freshness in food (Billesbølle et al., 2023). Their ability to amplify sensory signals makes them highly efficient, though their complexity can lead to challenges in drug development and targeting specific pathways (Billesbølle et al., 2023).

The importance of olfaction in freshness perception is significant. Contrary to older views that downplayed the human sense of smell, recent research emphasizes that humans are highly capable of detecting and interpreting scents for various social and emotional cues (Roberts et al., 2020). Neuroscientific advances reveal that the human olfactory bulb, though smaller than in some animals, is highly efficient, allowing accurate detection of freshness and other odors. The olfactory bulb processes olfactory information and relays it to higher brain regions, including the orbitofrontal cortex and limbic system, which are involved in decision making, emotion, and memory (Strous and Shoenfeld, 2006). This neural pathway explains why certain scents associated with freshness, such as citrus or mint, can evoke feelings of cleanliness, invigoration, and well-being (Sowndhararajan and Kim, 2016). The efficiency and complexity of the olfactory system enable humans to perceive freshness not only as a sensory input but also as an emotional and psychological experience.

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Psychological aspects in freshness perception

The perception of freshness extends beyond physiological mechanisms and is deeply intertwined with psychological factors that influence how individuals experience and interpret freshness. Cognitive processes, emotional responses, cultural backgrounds, and environmental contexts all play significant roles in shaping consumer perceptions of freshness (Lawless and Heymann 2010; Ozdogan et al. 2021). These psychological aspects determine not only the perception of sensory characteristics of products but also impact consumer preferences, satisfaction, and behavior (Barsyte et al., 2023; Ramirez et al., 2022). Understanding these factors is crucial for industries aiming to develop products and marketing strategies that align with consumer expectations and enhance the overall user experience.

Cognitive interpretation of freshness

The cognitive interpretation of freshness involves mental associations, expectations, memory, prior experiences, and learned knowledge that shape how individuals perceive and value freshness in products (Barsyte et al. 2023; Fenko et al. 2009). Consumers interpret sensory cues within a contextual framework influenced by personal and cultural factors. This cognitive processing allows individuals to assign meaning to sensory inputs, affecting their perception of freshness.

Mental associations are formed through repeated experiences and exposure to certain products or environments. For example, the scent of citrus may be associated with cleanliness and freshness due to its common use in cleaning products (Fenko et al. 2009). Expectations based on product packaging, branding, and marketing messages also influence how freshness is perceived (Barsyte et al. 2023). If a product is marketed as "fresh" or "natural", consumers may be more likely to perceive it as such, even if the sensory attributes are similar to other products.

Olfactory cues have a profound impact on psychological comfort and the perception of freshness. Jia et al. (2023) investigated how scents like peppermint and ginger affect psychological comfort in thermal environments. The study found that peppermint is perceived as cooler and more refreshing, enhancing subjective comfort in warm conditions, while ginger produces a sense of warmth, improving comfort in cooler environments. These olfactory stimuli interact with thermal perceptions, influencing sensations of warmth and coldness. The study highlighted that olfactory cues had a more pronounced effect on subjective comfort than thermal conditions alone, suggesting that the perception of freshness is heavily influenced by cognitive interpretation of sensory inputs.

The interaction between olfactory stimuli and environmental factors underscores the importance of context in sensory perception. Individuals interpret freshness cues based on their expectations and experiences within a given environment. For instance, a cool peppermint scent may enhance the perception of freshness in a warm setting by aligning with the expectation of cooling relief (Jia et al. 2023). This cognitive processing enables consumers to derive meaning from sensory cues, influencing their overall perception of freshness.

Emotional responses to freshness

Emotional responses to freshness are integral to shaping consumer attitudes and preferences, particularly in relation to well-being, mood, and sensory satisfaction (Ramirez et al. 2022; Yao et al. 2024). Freshness is often linked to positive emotional states such as invigoration, alertness, and rejuvenation, which enhance overall product experiences and contribute to a sense of well-being.

Freshness-related sensory stimuli can evoke specific emotional reactions. For instance, Ramirez et al. (2022) identified key drivers of refreshing perceptions in beverages, such as cooling sensations and light, fruity flavors, which are associated with enhanced alertness and mood improvement. Such sensory indicators are effective in eliciting emotional benefits, such as increased energy and revitalization, thereby positively impacting consumers' emotional engagement with products. Yao et al. (2024) demonstrated how citral, a scent associated with freshness, induces heightened arousal and attentional capacity, evidenced by larger pupil sizes and increased beta-gamma oscillations. These findings suggest that certain scents linked to freshness can activate neural mechanisms related to emotional arousal, promoting feelings of invigoration and mental clarity.

Emotional responses to freshness are supported by the activation of the brain's reward and emotional processing centers, such as the limbic system and orbitofrontal cortex (Herz, 2009; Sowndhararajan and Kim, 2016). The positive emotions elicited by freshness cues strengthen consumer satisfaction and product appeal, ultimately influencing brand loyalty and purchasing behavior. By understanding these emotional responses, marketers can design products and advertising campaigns that tap into consumers' desire for freshness-related emotional benefits.

Cultural and environmental influences on freshness

Cultural factors significantly shape the perception of freshness, with variations in expectations and standards observed across different societies (Barsyte et al., 2023; Dantec et al., 2022). Cultural background influences associations of certain colors, odors, and product characteristics with freshness.

Dantec et al. (2022) investigated cross-cultural perceptions of natural products and found that Americans favored higher intensity in natural product odors and colors, while French respondents more often chose white as representing natural products. Natural odors were associated with positive descriptors such as “fresh” and “light”, whereas unnatural odors were linked to terms such as “chemical” and “pungent.” These findings indicate that cultural differences play a role in how freshness is perceived, suggesting that marketing strategies should consider these variations in order to appeal to diverse consumer groups.

Barsyte et al. (2023) highlighted that consumers use non-sensory cues, such as the brand’s origin or the product’s journey from source to market, to judge freshness. Global brands are perceived as less fresh because they seem distant, leading to concerns about preservation and additives. This psychological distance makes global products seem less natural compared to local brands, which are seen as closer to the point of origin and thus fresher. Consumers with a high perceived vulnerability to disease are particularly sensitive to these freshness cues, associating freshness with self-protection instincts.

Environmental factors such as weather conditions, geography, and urbanization impact the perception of freshness by interacting with sensory systems (Bala et al., 2021). High temperatures can exacerbate the presence of pollutants like ground-level ozone, increasing the sensation of heaviness in the air and affecting freshness perception (Tian et al., 2021). Thermoreceptors in the skin detect temperature changes and send signals to the hypothalamus, regulating body temperature and comfort levels (Bautista et al., 2013). Elevated temperatures combined with pollution can amplify feelings of discomfort and sluggishness, negatively influencing the perception of freshness.

Air quality plays a crucial role in freshness perception. In urban environments with heavy traffic and industrial activities, the accumulation of pollutants degrades air quality, leading to a diminished sense of freshness (Bala et al., 2021). Visual cues such as visible haze or smog are processed by the visual cortex and are strongly associated with poor air quality. Conversely, rural or mountainous regions typically have cleaner air with fewer pollutants, often perceived as fresher and healthier environments. These environmental influences highlight the interplay between sensory perception and external factors in shaping the overall experience of freshness.

Indicators of Freshness Perception

The concept of freshness is not limited to food items but extends to various non-food products, where it plays an important role in consumer perception, satisfaction, and purchasing behavior (Fenko et al., 2009; Herz, 2009). In non-food products such as perfumes, personal care items, and air care products, freshness is often conveyed through sensory cues that enhance the overall user experience (Kumar et al., 2021; Zarzo 2012). Understanding the physiological indicators of freshness in these products is essential for manufacturers aiming to meet consumer expectations and create appealing products (Barsyte et al., 2023; Rodriguez et al., 2024).

From sensory indicators to freshness

Freshness in non-food products is primarily communicated through sensory attributes such as fragrances, textures, and visual appeal (Dantec et al., 2022; Fenko et al., 2009). These indicators play a significant role in enhancing user experience and influencing consumer perceptions of product quality and effectiveness (Herz, 2009; Sharmeen et al., 2021).

In the realm of perfumes, freshness is often associated with the use of highly volatile top notes such as citrus, green, and aquatic fragrances (Zarzo, 2012). Zarzo (2012) explored the relationship between odor freshness and substantivity in perfumery, revealing that fresh odors are typically linked to light, cool, and invigorating scents that evaporate quickly. These scents, such as lemon, bergamot, and mint, provide an immediate sense of freshness upon application and are perceived as energizing (Dantec et al., 2022; Fenko et al., 2009). However, the components that contribute to this fresh sensation can also lead to allergic reactions in some individuals, as certain fragrance ingredients used to enhance the fresh scent may act as allergens (Kumar et al., 2021).

For personal care products, such as shampoos, soaps, and lotions, the inclusion of fresh scents plays a crucial role in enhancing user satisfaction and perceived effectiveness (Kumar et al., 2021; Sharmeen et al., 2021). Fragrances such as peppermint, eucalyptus, and citrus are commonly used to evoke feelings of cleanliness, rejuvenation, and invigoration (Herz, 2009). Smooth textures and appealing visuals, including bright colors and elegant packaging, further contribute to the perception of freshness in these products (Fenko et al., 2009; Soto et al., 2018). Soto et al. (2018) evaluated personal care products formulated with natural extracts and found that color and odor were primary attributes driving consumer acceptance, with pleasant floral and earthy aromas enhancing the perception of freshness.

Similarly, air care products, such as air fresheners and scented candles, utilize fresh fragrances to improve ambiance and create a pleasant environment (Barsyte et al., 2023; Herz et al., 2022). Scents associated with nature, such as ocean breeze, fresh linen, or rainforest, are employed to evoke a sense of cleanliness and freshness in indoor spaces (Herz, 2009). These products aim to mask unpleasant odors and enhance indoor air quality, contributing to psychological comfort and well-being (Barsyte et al., 2023; Herz, 2009).

Visual cues are also crucial in conveying freshness for non-food products. Colors such as light green, blue, and white are often associated with freshness and are used in packaging and product design to convey this attribute (Dantec et al., 2022; Fenko et al., 2009). Fenko et al. (2009) demonstrated that while odor changes significantly affect the perception of freshness, color changes have less impact when the odor is fixed, highlighting the dominant role of olfactory cues in freshness perception.

Neurological responses to freshness

Fresh scents and sensory experiences in non-food products can activate specific brain regions associated with pleasure, well-being, and emotional responses (Rodriguez et al., 2024; Sowndhararajan and Kim, 2016). The olfactory system is closely linked to the limbic system, which is involved in emotion and memory processing (Herz, 2009; Sowndhararajan and Kim 2016). As a result, fragrances that evoke freshness can influence mood and physiological states.

Rodriguez et al. (2024) explored a novel multisensory approach to enhancing the perception of freshness in perfumes by integrating sound into the fragrance experience. Their study identified specific auditory characteristics, such as low tempos, mid-high pitch, and legato articulation, that evoke sensations typically associated with fresh scents, including coldness, lightness, and calmness. By combining these sounds with fresh fragrances, they enhanced the overall freshness perception, demonstrating that sensory modalities can interact to influence consumer experiences.

Fragrances with fresh scents have been shown to trigger neural mechanisms leading to emotional and physical responses such as increased alertness, reduced stress, and improved mood (Herz 2009; Sowndhararajan and Kim 2016). For instance, exposure to citrus fragrances can stimulate brain activity associated with invigorating effects, while mint scents may enhance cognitive performance and alertness (Sowndhararajan and Kim 2016). These effects are often measured through changes in physiological parameters such as heart rate, blood pressure, and electroencephalogram (EEG) patterns.

Herz (2009) highlighted that olfactory stimuli could have therapeutic benefits, influencing mood and emotional states. The direct connection between olfactory receptors and the brain's emotional centers allows fragrances to have immediate and potent effects on psychological well-being. Aromatherapy practices utilize fresh scents to promote relaxation, reduce anxiety, and enhance overall mood (Herz, 2009).

Furthermore, Dantec et al. (2022) found that consumers associate freshness with simplicity, cleanliness, and lightness, which are related to natural and fresh perceptions. The study also investigated positive semantic adjectives associated with freshness and found that certain odors, such as bergamot and peppermint, are strong indicators of freshness due to their ability to evoke these positive associations.

These neurological responses underscore the importance of sensory indicators in nonfood products and their impact on consumer well-being and satisfaction. By leveraging the neurological effects of fresh scents, product developers can create statements that not only appeal to the senses but also contribute to positive emotional and physiological outcomes (Herz, 2009; Sowndhararajan and Kim 2016).

Psychological response to freshness

Freshness in non-food products is often associated with positive emotional attributes such as cleanliness, purity, and renewal (Herz, 2009). These associations shape emotional connections to products and influence consumer behavior by enhancing satisfaction and brand loyalty (Barsyte et al., 2023; Herz, 2009).

Herz (2009) discussed how olfactory cues related to freshness can evoke emotional responses that impact mood and well-being. Fresh scents such as citrus and mint are related to feelings of cleanliness and invigoration, creating a positive emotional connection to the product. This emotional response can lead to increased consumer satisfaction and a stronger attachment to the brand.

Fresh scents can also enhance consumer perceptions of product efficacy and quality, influencing purchasing decisions and repeat usage (Herz, 2009). Barsyte et al. (2023) found that consumers perceive products with freshness cues as more natural and trustworthy, which can enhance brand loyalty. The lingering effects of freshness, such as a lasting scent after using a product, serve as a reminder of the product's effectiveness, reinforcing positive perceptions and influencing future purchasing behavior.

Consumer preferences for scented products such as air fresheners and cleaning items are driven by a holistic experience that integrates functional, in-use, and emotional benefits (Herz et al., (2022). These products not only mitigate malodors but also provide pleasant fragrances that enhance the in-use experience by making mundane chores more enjoyable. The emotional benefits include improved mood, reduced discomfort, and elicitation of positive memories, which contribute to the overall perception of freshness and influence consumer behavior (Fernandes and Moreira 2019; Herz et al., 2022).

Cultural influences and freshness

Cultural influences play a significant role in shaping perceptions of freshness, affecting how consumers interpret freshness cues in products (Dantec et al., 2022). Marketing strategies often leverage these cultural associations by using freshness cues in packaging and advertising to align products with consumer desires (Barsyte et al., 2023; Fenko et al. 2009).

The use of colors, imagery, and language in packaging and advertising conveys freshness and appeals to consumer preferences. Colors like blue and green are often associated with freshness and are used in product packaging to evoke feelings of cleanliness and naturalness (Fenko et al., 2009; Dantec et al., 2022).

Dantec et al. (2022) explored how cultural backgrounds shape consumer perceptions of freshness, finding that different cultures have varying associations with colors and scents. For instance, certain odors such as bergamot and peppermint are strong indicators of freshness due to their ability to evoke positive associations related to simplicity, cleanliness, and lightness. Understanding these cultural nuances allows marketers to tailor products and advertising strategies to meet the expectations of diverse consumer groups.

Aligning products with consumer desires involves emphasizing attributes such as cleanliness, well-being, and environmental responsibility (Barsyte et al., 2023). Brands may highlight natural ingredients, eco-friendly packaging, and ethical practices to enhance perceptions of freshness and appeal to consumers who prioritize sustainability (Barsyte et al., 2023; Fernandes and Moreira 2019). Barsyte et al. (2023) noted that consumers with a high perceived vulnerability to disease are particularly sensitive to freshness cues, associating freshness with self-protection instincts. By incorporating these values into product development and marketing, companies can foster stronger brand connections and influence consumer behavior.

Marketing strategies also utilize olfactory cues in retail environments to enhance the freshness experience (Rodriguez et al., 2024). For example, integrating specific auditory characteristics with fresh fragrances in stores can enhance sensory engagement and create a multisensory experience that reinforces the perception of freshness. This approach can increase consumer engagement, satisfaction, and ultimately influence purchasing decisions. A partial list of freshness indicators for non-food products has been summarized in Table 1.1.

Table 1.1: Partial list of indicators of freshness in non-food products

Product Category	Indicators of Freshness	Examples and Methods
Perfumes	Highly volatile top notes, invigorating scents (citrus, green, aquatic)	Use of lemon, bergamot, mint; measured through scent persistence and consumer preference (Fenko et al. 2009; Zarzo 2012)
Personal Care Products (e.g., shampoos, lotions)	Fresh scents such as peppermint, eucalyptus, citrus; smooth textures, appealing colors	Enhances feelings of cleanliness, rejuvenation; color and odor drive acceptance (Herz, 2009; Soto et al., 2018)
Air Care Products (e.g., air fresheners, candles)	Nature-related fragrances (ocean breeze, fresh linen); improvement in ambiance	Masking unpleasant odors, enhancing indoor air quality, measured through consumer satisfaction (Barsyte et al., 2023; Herz et al., 2022)
Visual Cues (Package)	Light colors (green, blue, white) associated with freshness	Used in packaging and product design to convey freshness; less impactful than odor when odor is fixed (Fenko et al., 2009)
Fragrances	Fragrances that trigger emotional and physical responses (alertness, mood enhancement)	Measured through changes in physiological parameters (heart rate, EEG) and emotional wellbeing (Rodriguez et al., 2024; Sowndhararajan and Kim 2016)

Understanding freshness in non-food products relies on a combination of sensory indicators, neurological responses, and cultural associations to shape consumer perceptions and behavior. By leveraging these elements, manufacturers can enhance product appeal, foster emotional connections, and influence purchasing decisions, ultimately contributing to consumer satisfaction and brand loyalty.

Techniques and Methods for Understanding Freshness

Advancements in technology have significantly enhanced the ability to analyze and understand freshness in non-food products. Various analytical instruments and techniques have been developed to objectively measure freshness indicators, assess quality, and predict shelf life (Song and Liu, 2018; Ozdogan et al., 2021). These methods enable researchers and industry professionals to obtain detailed insights into the physical, chemical, and sensory properties associated with freshness, facilitating improved quality control and product development (Cheng et al., 2015; Zhu et al., 2021). In this section, we discuss sensory methods that aid in the understanding of freshness perception, and various analytical techniques such as virtual reality (VR) and specific neuroimaging technologies, that have been instrumental in advancing the understanding of freshness.

Sensory research to understand freshness

Freshness is an important sensory quality that can influence acceptance of cosmetics and perfumes. Understanding the features that create a sense of freshness helps product developers make scents that appeal to consumers' emotions and senses. Studies have shown that qualities such as lightness, crispness, and floral notes are key factors in how people perceive freshness.

Sensory evaluations by trained panels are crucial in understanding the sensory characteristics linked to freshness. Unlike consumers, who may struggle to describe specific characteristics and differences, trained panelists can accurately identify and measure sensory properties. This helps guide product development to ensure that freshness attributes are present, consistent, and meet consumer expectations. Descriptive sensory studies typically follow several steps. First, a range of products are selected to represent different characteristics within the category, allowing panelists to become familiar with them. Then, a group of panelists are recruited—these panelists must pass acuity tests and often have prior experience. Next, the panel worked with researchers to create a list of 15-20 key terms describing the sensory properties of the product, such as appearance, aroma, and texture. Reference materials may be used to speed up this process (Sun et al., 2014). The panelists are then trained to use these descriptive terms consistently and accurately, and their skills are validated to ensure they can reliably evaluate the products. Once trained, the panelists use a quantitative sensory profiling method to describe the products' characteristics in detail, without expressing any hedonic opinions. This method is widely valued for its accuracy in describing sensory characteristics, which helps guide marketing and research decisions (Pense-Lheritier, 2015).

Descriptive sensory methods have been used to uncover the relationship between attributes related to freshness and various products (Lee et al., 2005; Depledt, 2009; Lukic et al., 2012). Vieira et al. (2020) investigated emollients in hand creams, examining characteristics such as smoothness, stickiness, and thickness, while also addressing freshness as a temperature-changing effect on the skin. However, limited research has specifically focused on the scent of freshness.

Results from both trained panel evaluations and consumer studies could highlight the key attributes that drive the perception of freshness. Trained panelists provide detailed descriptions of sensory properties, while consumer studies help understand how these attributes influence overall product acceptance. Research has shown that qualities such as lightness and floral notes significantly contribute to consumer preferences for freshness (Rodriguez et al., 2024). These products also tend to evoke positive emotions, enhancing the product's appeal.

Rapid sensory profiling methods, such as free mapping and free sorting, have also been used to quickly understand consumer perceptions (Faye et al., 2004). These methods are flexible and cost-effective, and could provide helpful insights into how freshness is perceived and how products can be positioned in the market. However, they lack the depth of analysis provided by trained panels, which is particularly important when subtle differences between products need to be assessed.

Instrumental research to understand freshness

Virtual Reality (VR)

Recent research emphasizes the increasing integration of olfactory stimuli in virtual reality (VR) environments to enhance human emotions, cognition, and memory recall. Traditionally, VR has focused on visual and auditory stimuli, but recent studies demonstrate the importance of olfaction as an additional sensory input that can significantly improve user experiences and serve as an analytical tool for neurological effects, such as freshness perception.

Figure 1.1 shows how neuron receptors react to different stimuli and how these reactions influence perception. It expresses how sensory inputs such as vision, sound, and smell interact to shape human experiences. In virtual environments, these findings are used to create immersive experiences that mimic real-world sensory experiences. By understanding how people perceive different stimuli, virtual environments can incorporate specific sensory cues, like smells, to make the experience more engaging and realistic. For example, olfactory stimuli can activate neuron receptors that affect emotions, memory, and cognition, leading to a richer and more immersive experience.

Bordegoni and Carulli (2023) highlight that incorporating olfaction in VR enhances user engagement, emotional immersion, memory recall, and task performance. Their study demonstrates that congruent odors significantly improve the sense of presence and user satisfaction, especially when odors are contextually appropriate within the VR setting. Similarly, Rantala et al. (2023) emphasized the role of congruent odors in enhancing memory recall, noting that participants interacting with VR environments, where odors matched the visual elements, recalled significantly more objects compared to incongruent or odorless environments. Rantala et al. (2023) also noted that congruent odors promote relaxed emotional states, which is valuable for measuring the perception of freshness in different contexts. Panagiotakopoulos et al. (2023) explored the advancements in digital scent technology, particularly within the Internet of Senses (IoS) framework, which aims to integrate multiple sensory inputs into a cohesive digital experience. Panagiotakopoulos et al. (2023) highlights the potential of digital olfaction in VR for applications such as marketing, healthcare, and communication, demonstrating how olfactory stimuli can increase emotional engagement and provide measurable insights into neurological effects. This emerging potential underlines the importance of multisensory VR environments for evaluating sensory perceptions, including freshness. Braun (2019) further investigated the emotional impact of olfactory integration in VR, identifying how pleasant odors evoke positive emotions, enhance mood, and improve overall user satisfaction. Braun's findings indicated that pleasant odors incorporated into VR experiences can elevate user mood and improve engagement, making them effective for assessing the neurological effects of freshness perception. By analyzing physiological and emotional responses, Braun suggests that olfactory stimuli are instrumental in evaluating freshness in both virtual and physical environments.

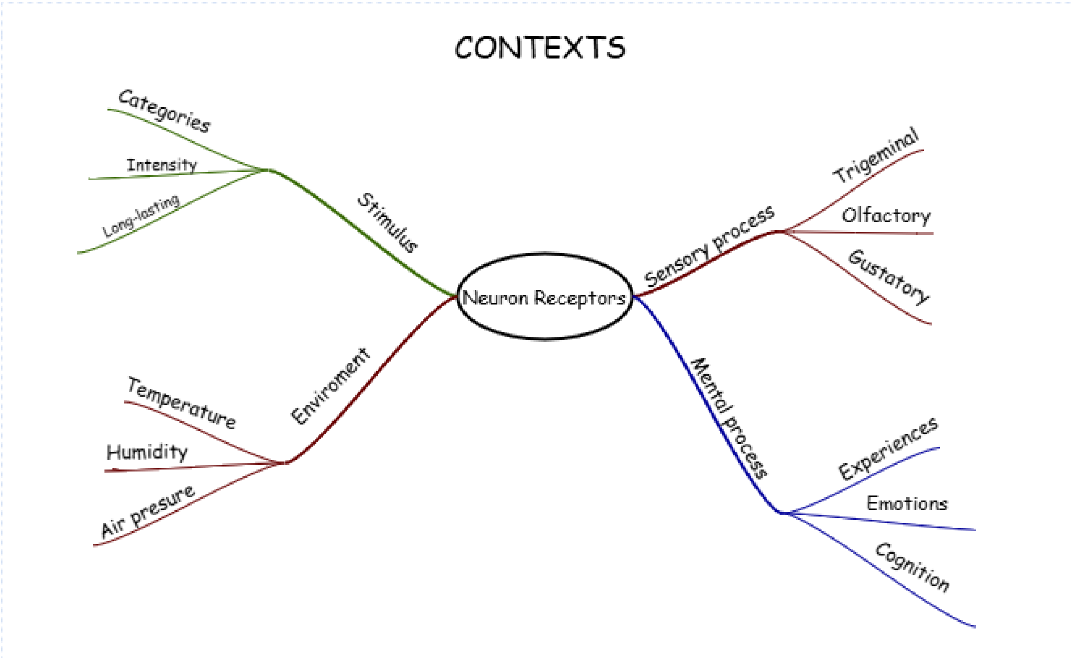

Figure 1.1 Concept map of virtual reality experience in sensory perception

Neuroimaging technologies

Neuroimaging technologies have become invaluable tools in studying the neural mechanisms underlying sensory perceptions, including the perception of freshness (Logothetis 2008; Han et al., 2020). Functional Magnetic Resonance Imaging (fMRI) and Electroencephalography (EEG) could allow researchers to observe and measure brain activity in response to freshness related stimuli, providing insights into how sensory inputs are processed and integrated at the neural level (Antequera et al., 2021; Guo et al., 2024). Understanding these neural correlations is essential for unraveling the complex interactions between physiological responses and sensory perception, which can inform product development and enhance consumer experiences (Han et al., 2020; Guo et al., 2024).

Functional Magnetic Resonance Imaging (fMRI)

Functional Magnetic Resonance Imaging (fMRI) is a non-invasive neuroimaging technique that measures brain activity by detecting changes associated with blood flow (Logothetis, 2008). When the brain region is more active, it consumes more oxygen, leading to increased blood flow to that area. fMRI captures these hemodynamic responses, allowing for the mapping of neural activity in response to specific stimuli (Logothetis, 2008). The example result is plotted in Figure 1.2a.

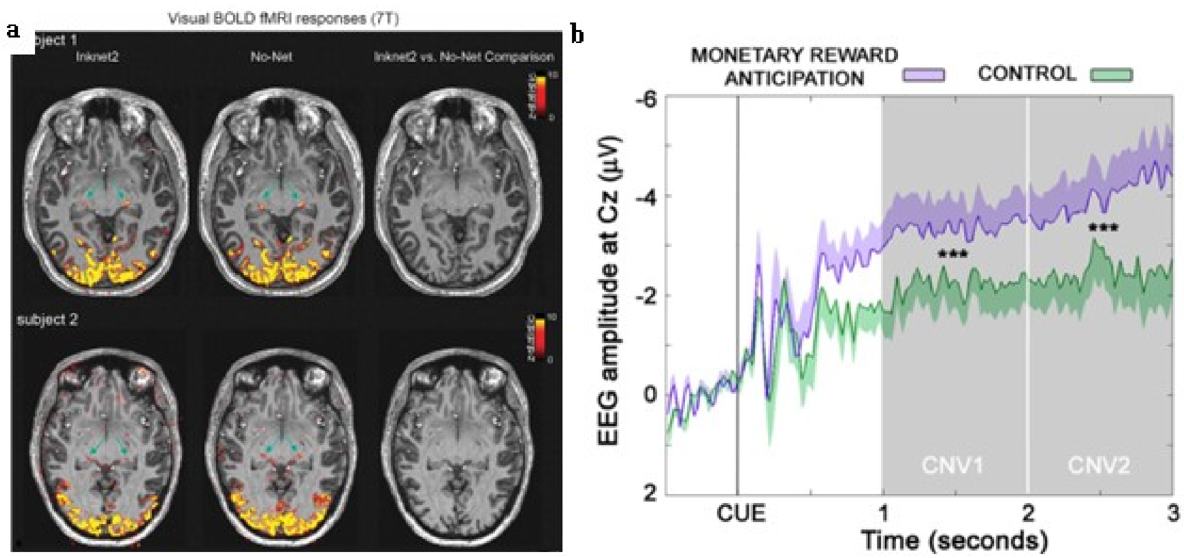

Figure 1.2 Example output image of a) fMRI (Cicero et al., 2024); and b) EEG (Plichta et al., 2013)

In the context of freshness perception, fMRI has been used to identify brain regions activated by freshness cues, such as olfactory and gustatory stimuli (Han et al., 2020). For example, exposure to fresh scents or flavors can activate the orbitofrontal cortex, insula, and limbic system, which are associated with sensory integration, reward processing, and emotional responses (Guo et al., 2024; Han et al., 2020). These regions contribute to the subjective experience of freshness by linking sensory inputs to pleasure and satisfaction.

Understanding the neural mechanisms involved in freshness perception through fMRI helps link physiological responses to sensory experiences (Logothetis, 2008). By identifying specific brain areas and neural pathways associated with freshness, researchers can gain insights into how sensory information is processed and how it influences behavior and preferences (Han et al., 2020). This knowledge can inform the development of products that effectively stimulate desired neural responses, enhancing consumer satisfaction and engagement.

However, fMRI has limitations, including relatively low temporal resolution and susceptibility to artifacts caused by head movement or physiological noise (Logothetis, 2008). Additionally, fMRI primarily measures indirect indicators of neural activity (hemodynamic responses), which may not capture the full complexity of neural processing (Logothetis, 2008). Despite these challenges, fMRI remains a powerful tool for exploring the neural correlates of sensory perception and has contributed significantly to our understanding of freshness perception at the neural level.

Electroencephalography (EEG)

Electroencephalography (EEG) is a neuroimaging technique that records electrical activity generated by neuronal firing in the brain using electrodes placed on the scalp (Antequera et al., 2021; Guo et al., 2024). EEG offers high temporal resolution, allowing researchers to track real-time brain responses to sensory stimuli, including freshness-related cues (Guo et al., 2024). The example result has been plotted in Figure 1.2b

EEG has been applied in olfactory research to develop objective measures of olfactory responses and to understand how the brain processes freshness-related scents (Guo et al., 2024; Sowndhararajan and Kim, 2016). Guo et al., (2024) introduced the Olfactory Perception Dimensional Space (OPDS), a method combining feature engineering and ensemble learning to classify odor perceptual attributes based on EEG data. By analyzing EEG patterns, they were able to objectively quantify olfactory responses and distinguish between pleasant and unpleasant odors, demonstrating the potential of EEG in capturing subtle perceptual differences related to freshness.

EEG allows for the examination of brain oscillations and event-related potentials (ERPs) associated with sensory processing (Antequera et al., 2021). For example, exposure to fresh scents may induce specific EEG patterns, such as increased alpha wave activity associated with relaxation or increased beta-gamma oscillations linked to heightened arousal and attention (Sowndhararajan and Kim, 2016; Yao et al., 2024). These neural signatures provide insights into the emotional and cognitive responses elicited by freshness cues.

Applications of EEG in olfactory research extend to evaluating the effectiveness of fragrances, understanding consumer preferences, and informing product development (Antequera et al., 2021; Guo et al., 2024). EEG offers a cost-effective and accessible method for real-time monitoring of brain activity, making it a valuable tool for studying the neural basis of freshness perception.

However, EEG has limitations in spatial resolution, making it challenging to localize specific brain regions involved in sensory processing (Logothetis, 2008). It is also susceptible to muscle movements and external electrical interference. Despite these challenges, EEG's high temporal resolution and non-invasiveness make it a complementary technique to fMRI in exploring the neural mechanisms of freshness perception.

Emerging techniques to understand freshness in non-food products

Hyperspectral Imaging (HSI) is a non-invasive, rapid analytical technique that integrates imaging and spectroscopy to capture spatial and spectral data from a sample (Cheng et al., 2014; Ozdogan et al., 2021). In the food industry, HSI has been used to assess sensory properties such as texture, color, surface defects, flavor, and the quality or extent of spoilage. (ElMasry & Nakauchi, 2016; Xie et al., 2015). HSI captures images across a wide range of wavelengths, producing a three-dimensional data cube that provides detailed information about chemical composition and physical structure (Cheng et al., 2014). Regression models like Partial Least Squares Regression (PLSR) and classification models such as Support Vector Machines (SVM) and Artificial Neural Networks (ANN) are commonly applied to interpret hyperspectral data for predicting attributes and categorizing freshness levels (Kamruzzaman et al., 2012; Cheng et al., 2015; Zhang et al., 2022). Despite advantages such as rapid analysis, non-destructive testing, and minimal sample preparation, challenges remain, particularly in data processing due to the high volume of data, as well as the cost of equipment (Cheng et al., 2014; ElMasry & Nakauchi, 2016). Ongoing advancements in machine learning and data algorithms are helping overcome these challenges, expanding the use of HSI in food quality assessment (Lin & Sun, 2020; Wang et al., 2019; Zhu et al., 2021). Although HSI is widely used in the food industry, its application to non-food products remains limited. Given its ability to analyze the spatial distribution and chemical composition of compounds, HSI could potentially be used to identify volatile compounds in perfumes, monitor changes in their composition over time, and ensure consistency in product quality. This represents an opportunity for future research to investigate its applicability in the scent area.

White Space and Future Directions

While significant progress has been made in understanding freshness from both physiological and psychological perspectives, there remains a critical need for standardized tools to measure freshness perception comprehensively. One major gap identified is the lack of a holistic scale that integrates physiological effects with psychological perceptions of freshness in scents. Developing such a scale would enable researchers and industry professionals to assess freshness perception more accurately and consistently across different contexts and products.

To address this gap, this research focuses on the development and validation of a new scale that measures consumers' perceptions of freshness in scents. This scale would encompass various factors that influence freshness perception, including sensory attributes, emotional responses, and environmental effects. Freshness is a concept that includes both food and non-food products. While for foods the concept of freshness is more related to quality features and cues of spoilage, for non-foods is more related to fragrances and scents, especially for personal and home care products. In this research, we will be focusing on the perception of freshness of scents used at home. The following research objectives are proposed:

- Explore descriptors and factors that contribute to freshness perception of home scents.
- Develop a uniform and reliable scale to measure consumers' overall freshness perception in home scents, integrating both physiological and psychological dimensions.
- Validate the scale through empirical studies, ensuring its applicability across different product categories and consumer groups.

To achieve these objectives, a multi-method research approach is recommended. Initially, qualitative methods such as focus groups, and in-depth interviews will be employed to identify key factors and dimensions of freshness perception from the consumer's perspective. This exploratory phase will ensure that the scale captures all relevant aspects of freshness as experienced by consumers.

Subsequently, quantitative methods involving a large-scale survey and product application will be used to test and refine the scale. Statistical techniques such as factor analysis can help determine the underlying structure of the scale and validate reliability and validity. By involving diverse consumer groups, the scale can be tested for generalizability across different demographics and cultural contexts.

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Chapter 2 - Investigating Freshness Perception Using Focus Groups and E-commerce Comment Reviews

Introduction

Human perception of aroma and flavor is influenced by a multitude of factors, demonstrating considerable variation among individuals. This diversity in sensory perception is primarily attributed to cultural backgrounds, educational levels, and various psychological factors, as well as physiological elements such as health status and neurological function (Asioli et al., 2017).

As Koster and Mojet (2015) noted, people's responses to identical stimuli can markedly differ. Their research showed variations in sensitivity to specific concentrations of salt solutions. Some participants readily discern the salty taste, while others do not (Hayes et al., 2010). Notably, older populations, particularly those aged 65 and above, face pronounced challenges in identifying flavors, often struggling with this basic sensory activity (Methven et al., 2016). Furthermore, a study by Cheng (2020) on the perception of ethnic foods such as powdered milk, revealed that cultural familiarity significantly influences how participants with a Chinese background perceived aromas compared to their US and Irish counterparts (Cheng et al., 2020).

In the field of product development and sensory science, understanding the sensory properties of products remains inherently complex. Descriptive Analysis, developed to address the challenges of capturing nuanced sensory characteristics, requires standardized training for panelists to ensure consistent identification of these attributes (Lawless and Heymann, 2010). Under controlled environments and strict evaluation protocols, these trained panelists provide reliable, quantitative data on a comprehensive list of sensory characteristics, defining each product's attributes and their intensity levels. Despite the rigor of this approach, it is notably time-consuming and requires extensive preliminary training, with retraining needed before commencing each new project to maintain accuracy and consistency in results. Therefore, many rapid sensory methods have become important to accommodate individuals without formal training. Correspondingly, methods for analyzing data from these rapid sensory approaches, such as binary data, have also been widely applied in the sensory and consumer research field (Jaeger et al., 2015; Heussen et al., 2020).

Focus group discussions are a widely used method in sensory research to understand consumer perceptions, opinions, and behaviors. They provide an opportunity for researchers to hear directly from participants about their thoughts, experiences, and personal stories. This method helps reveal how factors such as cultural background, personal experiences, and individual preferences shape the way people understand specific product attributes. The open, interactive environment of focus groups encourages participants to share spontaneously, leading to new ideas and associations. These insights may not be captured through other methods like individual interviews or structured surveys. In the study of non-food products, these spontaneous conversations could be key to understanding consumer terminology and the different ways people interpret and experience terms such as fresh or refreshed (Talavera and Sasse, 2019). Freshness is a complex quality and focus groups may help researchers capture its various meanings and/or dimensions, as understood by different individuals.

The dynamic nature of focus groups also allows for the integration of other consumer-friendly sensory methods. For example, techniques such as Sorting, Check-All-That-Apply (CATA) and Mapping can be easily incorporated into a focus group setting (Ares et al., 2015; Jaeger et al., 2015; Lahne, 2020; Lahne et al., 2016). These methods involve participants mapping and sorting products based on their similarities and differences. By doing so, researchers can gather valuable information on how consumers perceive different products and the sensory attributes that define them. This type of sorting activity helps identify key characteristics that influence consumer preferences.

In addition to mapping exercises, focus groups also allow participants to use their own language to describe sensory experiences. This is important because it captures natural, unaided terminology that participants use to express their perceptions. These terms can then be used to develop sensory descriptors that are meaningful to consumers. Collecting terminologies without imposing pre-defined categories ensures that the language used is relevant and authentic to the participants' experiences.

Statistical analysis to support findings

To further support the findings from both focus groups and E-commerce comment analysis, additional statistical methods were employed. Multiple Factor Analysis (MFA) is one such technique used to visualize the relationships between descriptors derived from focus groups and those obtained through topic modeling. MFA helps in reducing the dimensionality of the data, allowing researchers to see patterns and similarities between different freshness attributes. This visualization makes it easier to identify clusters of attributes that are perceived similarly by consumers.

Another useful approach is the analysis of binary data collected during focus groups, where participants independently identified specific attributes. If an attribute was perceived and noted by a participant, it is recorded as 1 in the matrix; otherwise, it is recorded as 0 for analysis. A traditional method for evaluating relationships among attributes is the Chi-Square hypothesis test, which shows if significant associations exist. However, this approach mainly highlights marginal relationships rather than conditional relationships (Banerjee et al., 2008; Wainwright et al., 2008). To better understand the conditional dependencies between attributes, the binary data can be analyzed using an Ising model, estimated via logistic regression. The Ising model allows researchers to evaluate how the presence of one attribute influences the likelihood of others being identified. Methods such as neighborhood selection or other logistic regression-based approaches are typically used to explore these conditional dependencies (Banerjee et al., 2008; Ravikumar et al., 2010; Wainwright et al., 2008). These statistical analyses provide a structured approach to validate and expand upon the qualitative findings, ensuring that the conclusions drawn are robust and reliable.

E-commerce comment analysis using topic modeling

In addition to focus groups, online consumer reviews provide another valuable source of information to understand perceptions of freshness in air care products. E-commerce comments from platforms such as Amazon, Sephora, and other product review sites allow researchers to gather a large volume of unstructured consumer feedback. To analyze these reviews, topic modeling techniques like Latent Dirichlet Allocation (LDA) are used to extract key themes and dimensions associated with freshness. This approach helps identify specific descriptor terms commonly used by consumers, such as "clean," "citrusy," or "outdoor breeze," which may not emerge during focus group discussions.

Topic modeling is particularly useful for providing a broad perspective on consumer perceptions by analyzing a vast number of reviews. It helps researchers understand what freshness means to consumers in a more generalized way, capturing a diverse range of associations. While focus groups provide in-depth, context-rich insights into how people perceive freshness, topic modeling offers breadth by summarizing themes across many consumers' experiences. Together, these methods help establish a comprehensive set of sensory descriptors that are both relevant and data driven.

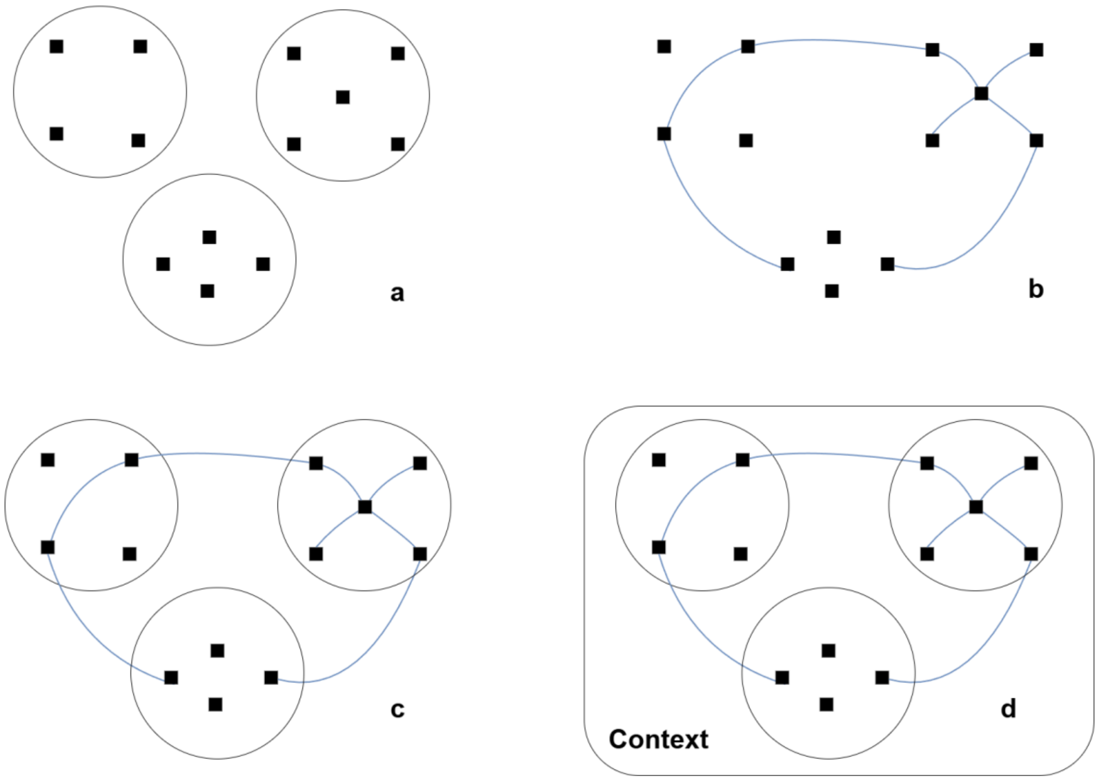

Figure 2.1: Underlying relationship among attributes

Figure 2.1 illustrates the evolving understanding of relationships among attributes and dimensions through different methods used in this study. Initially, Multiple Factor Analysis (MFA) results (Figure 2.1a) reveals the underlying factors that group related attributes, providing a potential understanding of how freshness in air care products is experienced. Then, graphical modeling techniques (Figure 2.1b) are employed to help uncover the conditional relationships between individual attributes of these air care products. By combining insights from MFA and graphical modeling and incorporating qualitative observations from focus group discussions (Figure 2.1c), researchers can potentially uncover underlying factors or relationships between attributes that may not be detected through single-factor analysis alone. Finally, E-commerce comment analysis using topic modeling provides an overall context and broader perspective, integrating these insights within a larger consumer viewpoint (Figure 2.1d).

This study was designed as exploratory research to investigate the potential dimensions and descriptor terms related to freshness using both focus group discussions and E-commerce comments. The primary goal was to understand consumer experiences related to freshness in air care products. The specific objectives were: 1) to identify the main dimensions of freshness as perceived by air care product users, and 2) to extract key descriptor terms related to each dimension of freshness. By combining insights from focus groups and E-commerce comments, the study aimed at creating a comprehensive understanding of how freshness is perceived and described by consumers, ultimately contributing to better product development and consumer satisfaction

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Materials and Methods

Samples

This study evaluated 12 samples, coded PR-A through PR-G, all from the same product category and commercially available in the US market (Table 2.1). Samples were prepared 24 hours before evaluation. Eight paper wicks were soaked in 15 ml of each air freshener product for 12 hours. Each wick was then placed into a 60 ml brown opaque bottle, which was marked with a unique, randomly assigned three-digit code to ensure anonymity and avoid bias, and covered with a black lid one hour before the evaluation. For the evaluation, each participant received one bottle of each product, a total of 12 bottles.

Table 2.1: Product aroma character descriptions

Product	Aroma Character Description
PR A	Bamboo and Waterlily
PR B	Sweet, Nutty, Maple syrup, Waffles and pumpkin.
PR C	Apple, Wild Daisies, Pink Peonies
PR D	Rose Petals, Ivy, Spring Musk
PR E	Creamy, Sweet treat cashmere, Florals, vanilla and sandalwood.
PR F	Melon, Raspberry Nectar, Italian Lemon
PR G	White flowers and Melon
PR H	Fresh sea salt & island flowers
PR I	Fresh linen
PR J	Ripe Pineapple; Hibiscus; Peach Nectar
PR K	Exotic papaya & hibiscus flower
PR L	Crisp air & freesia

Participants

To ensure a diverse range of opinions, the study used screening criteria focused primarily on age and educational background. Participants were selected within the age range of 18 to 54 years. Additional screening included questions about job types, lifestyle agreements, and moderate to heavy users of fragrances to guarantee a variety of perspectives. This approach aimed at enriching the discussion sessions with a wide array of experiences and viewpoints. Upon meeting the qualifications, individuals were contacted via phone to brief them on the discussion topics, pre-discussion assignments, and the incentives for participation. To promote open and varied dialogue, sessions were stratified into three age groups: 18 to 35, 26 to 45, and 36 to 55 years, facilitating dynamic and multilateral conversations. The study was conducted with a total of 20 participants to ensure a representation of consumer opinions and experiences (Table 2.2).

Table 2.2: Participant information for each of the three focus groups conducted

Group	Number of Participants	Age	Gender	Location
1	6	18 - 35 years	Two males, four females	Olathe, KS
2	8	36 - 55 years	Two males, Six females	Olathe, KS
3	6	26 - 45 years	One male, five females	Olathe, KS

Focus group discussion and data collection

Before the focus group discussion, participants participated in a warmup exercise to the concept of freshness through a "homework" session conducted a week earlier. They received instructions by email (see Appendix C) asking them to think about what freshness in scents means to them. Participants were also asked to recall an air care product they had used that made them feel fresh, and to reflect on the scents and their associated feelings. To visually represent these thoughts, they created a collage using pictures from sources such as internet printouts, magazines, newspapers, drawings, and/or sketches. These pictures could depict the products, emotions, or how they felt while using air care products. Participants were required to bring a physical copy of their collage to the discussion session. This activity is aimed at helping participants formulate their own opinions about the concept of freshness.

The discussion flow of focus group includes five major steps and has been listed in Figure 2.3. In a structured focus group, participants began with personal introductions, which transitioned into discussions about their assigned collage homework (Appendix C) depicting their personal experiences of freshness for any air care products. Participants were invited to explain how these product experiences made them feel "fresh". The moderator steered these discussions towards a comprehensive exploration of air care, systematically categorizing and defining its various aspects as recorded on a large notepad. Participants assessed the perceived benefits of air care products, and to capture their emotional and attitudinal responses, they were provided with sticky notes to jot down single-word reactions related to the meaning of freshness for them. This format was important to make sure that the terms participants used, were personal, and not influenced by others' terms. After these sections, participants completed subsequent free mapping sessions.

In the free mapping section, each participant arranged 12 products on an A3 size grid worksheet based on their perceived levels of freshness. The instructions emphasized that there were no correct or incorrect answers, encouraging spontaneous organization of products. Participants were instructed to use the entire space of the worksheet to position products. The products were closer together if they felt the products were more similar in conveying any terms, and further apart if they were less similar. The only requirement was that the participants' reason for grouping the products had to be explained. Therefore, participants were encouraged to write down the attributes of dimensions or groupings they used in their mapping, integrating the subjective nature of the task and the focus on individual perceptions of product freshness.

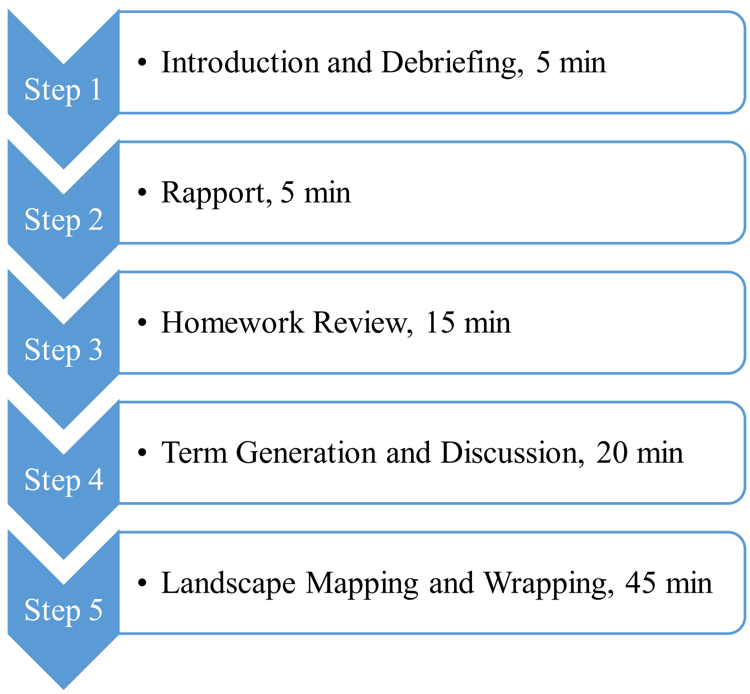

Figure 2.2: Focus group discussion flow

The dataset derived from this section of the focus group sessions consisted of spatial coordinates representing the placement of products on a two-dimensional mapping plane and a set of qualitative descriptors. Participants might place Product A and Product B closely on the plane, indicating a similar perception of freshness, and describe them with terms like 'crisp' or 'clean', while placing Product C further apart with descriptors like 'mild' or 'green'.

The structured data collected was such that each row represented a product, with columns capturing the X and Y coordinates from the mapping exercise and the frequencies of the associated descriptors. This matrix form allowed for the application of Multiple Factor Analysis (MFA) to quantify and visualize the relationships between products based on their sensory attributes and the emotional terms used by consumers to describe them. The details of discussion guide are listed in Appendix B

E-commerce comments

A comprehensive analysis was conducted on 32,104 online product reviews collected from Amazon and Walmart websites using a web scraping software—Parsehub (Toronto, Ontario, Canada). For Amazon reviews, only those written by verified purchasers were included. Each review provided information about product comments and product ratings, offering valuable insights into 12 different air freshener products, including their price points and sensory attributes.

Text processing

All data were processed in the tidy text format (Wickham, 2014) using R (R Core Team, 2020). Two main packages were used for data preparation and exploration: tidyverse (Wickham et al., 2019) and tidytext (Silge & Robinson, 2016). To prepare the data for word frequency analysis and topic modeling, the first step was to clean the data at the review level. Reviews with fewer than 10 words were removed since they provided little useful information about the product. Then, all reviews were split into unigrams (individual words) and bigrams (pairs of words). Bigrams helped capture word combinations and context that single words could not provide. Common stop words such as "the," "of," and "to" were removed, as they added no information to the analysis. However, "not" was kept when working with bigrams to make the tokens more meaningful. Additionally, a custom list of words was created for removal. This included dominant words such as "hand," "cream," and "lotion" that overshadowed other topics, as well as words like "Amazon," "review," and brand names that did not add useful information. To deal with the sparsity of bigram counts, stemming was applied to the words in bigrams, which involves cutting off the end of words to make them more general and group similar terms together (Bouchet-Valat & Bouchet-Valat, 2015). Stemming was not applied to unigrams in order to preserve the original features of the words. These natural language processing procedures have been widely used in both food and non-food studies to explore consumers' terminologies (Hamilton and Lahne, 2020; Zhang, 2021).

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Analysis

All focus group sessions were audio recorded, and the transcripts of each session were summarized. The qualitative results were derived from discussions and answers to the questions. Data were analyzed using the Constant Comparison method as described by Yu (2020). Explanations and descriptions from the product mapping session were gathered and compared to the plot results to serve as supporting evidence.

Multiple factor analysis

The data from the free mapping section was analyzed using Multiple Factor Analysis (MFA), as implemented in the R package FactoMineR. The data were arranged into an 81-column matrix, with 12 rows representing the products. The initial 42 columns detailed the X and Y coordinates assigned by the first panel, spread across 21 placements, while the remaining 39 columns contained the descriptors as evaluated by the second panel. We further excluded the terms with frequencies lower than 5. This matrix layout allowed MFA to integrate the diverse data types effectively, extracting common factors and providing a consensus configuration. This, in turn, showed the underlying dimensions in the data, revealing patterns and associations between the physical placement of the products and the evaluative descriptors, as perceived by the two separate panels Pages (2005).

Logistic regression with LASSO for Ising model

As further support, the attributes from the free mapping sections were analyzed using the Ising model with logistic regression. This analysis examined whether the relationship between attributes were conditional on other attributes. We applied the regularization method, LASSO, to help select important variables. The *GLMNET* package in R was used to fit the logistic regression-based model, which allowed us to find connections between variables by treating each one as a target in turn. We used cross-validation to find the best value for the penalty parameter, which made our model more reliable. We also used stability selection to make our results more robust. This involved running the model 100 times on different parts of the data, each time using 70% of the original data. Only the variables that were consistently selected across these runs were kept in the final model. This helped us avoid including variables that might be important by chance. To visualize these relationships, we used network graphs. This approach helped us understand how different attributes interact and find important patterns in binary data.

Topic modeling

Topic modeling was conducted on the entire dataset using Latent Dirichlet Allocation (LDA) to identify key themes or underlying topics in the text from E-commerce comments (Blei et al., 2003). LDA is a popular method for topic modeling that treats each document as a mixture of topics and each topic as a mixture of words. This approach allows documents to overlap in terms of content, reflecting the natural use of language (Blei et al., 2003; Silge & Robinson, 2017). LDA is a 'bag of words' technique, which means it does not consider the order of tokens, potentially missing important word collocations. To address this limitation, both unigrams and bigrams were used in the topic modeling. Additionally, to reduce sparsity in the document-term matrix, only frequently occurring unigrams and bigrams (appearing at least five times) were included in the LDA model. This process has been used in understanding consumers' product experiences with hand creams(Zhang., 2021).

Topic modeling was used to integrate and shape the results from the focus group discussion, providing a more comprehensive understanding of the dimensions and terms associated with freshness.

Results

Focus group discussion results

Physiological dimensions of the freshness perception

The physiological dimensions of freshness can be described through various sensory, environmental, and product-related aspects. Freshness is often related to specific scents, atmospheric influences, and delivery methods that evoke physiological responses. These dimensions help understand how individuals perceive freshness and how it influences their experience of the environment and products. The details of the dimensions are summarized in Table 2.3.

The sensory character of freshness includes several subdimensions, such as clean scents, floral scents, fruity scents, crisp scents, and light scents. Clean scents, represented by the terms "clean," "outdoor," "cold," and "hygienic," are commonly associated with environments that feel pure and uncontaminated. In the discussion, participants described how fresh sheets, or the smell of lavender could evoke a sense of cleanliness and renewal, associated with these clean scent characteristics. For example, participants said, "I use fresh sheets, and when I have fresh sheets, I spray them with lavender." Floral scents, including lavender and eucalyptus, were highlighted for their calming effect and ability to bring a sense of nature indoors. Participants mentioned, "I like the smell when I'm going to sleep"; “it helps me sleep better, and I have a spray that I use on my pillow or sheets." Fruity scents, such as apple cinnamon, were often related to cozy, homely feelings, particularly in seasons like winter. Participants expressed, "It makes me want to cozy up and read a book, and just creates a cozy atmosphere." Crisp scents, described simply as "crisp, sharp, refreshing sensory responses,” while light scents were noted as "subtle" or "non-overpowering". Participants indicated that scents should provide freshness without being overwhelming, allowing for a comfortable background aroma.

Table 2.3: Physiological dimensions of scents

Physiological Dimensions		
Dimension	**Subdimension**	**Terms**
Sensory character	Clean scents	Clean, Outdoor, Cold, Hygienic
	Floral scents	Floral, Cut Grass, Eucalyptus, Lavender, Calming
	Fruity scents	Citrus, Lemon, Fruity, Apple cinnamon
	Crisp scents	Crisp
	Light scents	Light, Subtle, Non-overpowering
Environmental interaction	Cozy atmosphere	Cozy, Sugar cookie
	Seasonal influence	Holiday scents, Winter scents, Spring scents
	Air quality	Good air quality, Fresh air, Fresh home, Fresh environments
Product delivery	Product forms	Candles, Diffusers, Sprays, Long-lasting scent, Continuous freshness, Masking aromas, Covering unpleasant smells
	Simple scents	Simple, Single-note, Straightforward freshness

The environmental interaction dimension focuses on how scents influence the perception of the space around an individual. This dimension includes subdimensions of cozy atmosphere, seasonal influence, and air quality. The cozy atmosphere subdimension, represented by terms like "cozy" and "sugar cookie," reflects how scents contribute to a comfortable and home environment. Participants mentioned sugar cookie scents as evoking memories of baking with family, associated with a nostalgic, cozy feeling. Participants stated that "They make me remember my childhood and baking cookies with my mom during Christmas time, so that smell makes me feel good". Seasonal influence, including "holiday scents" and "winter scents," relates to freshness at different times of the year, as participants described using different fragrances to reflect the mood of seasons like Christmas. Participants stated that "I find myself lighting candles more often during winter and Christmas." Lastly, air quality, with terms like "good air quality" and "fresh home," associated with the importance of a fresh environment. Participants discussed the role of scents like eucalyptus in maintaining a clean and breathable atmosphere, especially during colder months. For example, participants said, "I like to diffuse it, and use it as a spray; it helps with air quality for my kids."

The product delivery dimension describes the forms through which freshness is introduced to an environment, including product forms and simple scents. Product forms, such as "candles," "diffusers," and "sprays," are instrumental in maintaining long-lasting freshness, masking unwanted odors, and providing a sense of cleanliness. Participants mentioned using candles, diffusers, and sprays to enhance the feeling of freshness in their homes, whether to create a calming atmosphere or to mask less pleasant smells, for example, from pets. Participants mentioned, "I use candles a lot. I choose them because they're festive and make me feel cozy." Simple scents, described as "single-note" or "straightforward freshness," associate to easily recognizable experience of freshness. This was evident when participants talked about scents like lavender or lemon as straightforward and refreshing, contributing to a simple yet effective ambiance. For example, participants stated that "I like simple scents like lemon and lavender; they are clean and fresh, nothing overpowering."

Psychological dimensions of freshness

The psychological dimensions of freshness can be explained by exploring emotional, nostalgic, cognitive, and productivity-related effects that freshness evokes. These dimensions help in understanding the deeper psychological impacts of freshness on individuals, including how it influences emotions, memories, mental states, and overall well-being. The details of the dimensions are summarized in Table 2.4.

The emotional effect of freshness is characterized by positive emotions and mood influence. Freshness often evokes feelings of happiness and positivity. Participants described how fresh scents could enhance their mood, making them feel emotionally uplifted and calm. Terms like "positive emotions" and "happiness" reflect the pleasant emotional state triggered by fresh scents. Participants mentioned, "The smell just makes me feel happier and puts me in a better mood." Additionally, mood influence refers to how freshness contributes to emotional improvement, calmness, and relaxation. Participants indicated that fresh scents helped reduce stress, making the environment feel more relaxing. For example, participants mentioned, "The scent makes me feel calm and relaxed, especially after a long day."

Table 2.4: Psychological dimensions of scents

Psychological Dimensions		
Dimension	**Subdimension**	**Terms**
Emotional effect	Positive emotions	Positive emotions, Happiness, Wellbeing, Contentment, Joy, Excitement
	Mood influence	Mood enhancement, Emotional improvement, Calm, Relaxation, Stress relief, Stress reduction, Calm atmosphere, Comfort, Seasonal comfort, Relax
Nostalgic memories	Nostalgia	Familiar scents, Positive past experiences
Cognitive and mental effect	Well-being	Health, Positive state
	Focus	Focus, Concentration, Mental clarity
	Productivity	Productivity, Efficiency, Work performance
	Renewal	Starting new, Refreshing change, Rejuvenation, Invigoration, Fresh feeling

The nostalgic memories associated with freshness are highlighted by familiar scents and positive past experiences. Freshness has the ability to evoke nostalgic feelings, reminding individuals of positive moments in their lives. Participants frequently mentioned that certain scents, such as sugar cookies or floral notes, reminded them of childhood or family gatherings. For instance, participants recalled, "The scent reminds me of baking with my mom during the holidays, which brings back a lot of good memories." These nostalgic connections enhance the emotional value of freshness, creating an intimate bond between the scent and personal memories.

The cognitive and mental effects of freshness include aspects like well-being, focus, productivity, and renewal. Freshness contributes to well-being, providing a sense of health and positivity. Participants expressed how fresh environments helped them feel healthier and more mentally refreshed. For example, participants stated, "The fresh scent makes me feel healthier, like the space is cleaner, and it positively affects my mood." Freshness also aids in focus and concentration, enhancing mental clarity. Many participants mentioned that using fresh scents in their workspace helped them concentrate better. "The scent helps me focus on my tasks, especially when I need to concentrate," participants mentioned. Productivity is another aspect influenced by freshness, as fresh scents are associated with improved efficiency and work performance. Participants highlighted how a fresh-smelling environment made them feel more productive, for instance, "Having a fresh scent in my workspace makes me feel more motivated and efficient." Renewal is also an important subdimension, as freshness is often related to feelings of starting new, refreshing change, and rejuvenation. Participants expressed how fresh scents gave them a renewed sense of energy and a feeling of starting over, for example saying, "The scent makes me feel like everything is new and refreshed, giving me a sense of renewal." " This renewing effect of freshness plays a crucial role in enhancing the overall experience of an environment, making it feel revitalized and invigorating."

Product mapping results

Multiple factor analysis results

The multiple factor analysis can help to reduce the number of dimensions in original dataset and help researchers to focus on some specific factors or important underlying factors. The factors are ranked based on their eigenvalues. Researchers always choose the factors with eigenvalues from large to small.

According to the scree plot in Figure 2.4, which displays the eigenvalues for each dimension, illustrate how much variance each dimension explains. Dimension 1 has the highest eigenvalue (7.76), indicating that it captures the most variance, 27% of variances. Dimension 2 also explains 15% of variances. Dimension 3 and Dimension 4 explained 11% and 10% respectively. In total, Dimensions 1 through 4 have eigenvalues greater than 2.9, and capture over 63% variances which suggests that these dimensions are key contributors to understanding the data structure. Beyond Dimension 4, the variances begin to drop below 9% and eigenvalues below 2.5, indicating that the subsequent dimensions contribute less and may not add value for interpretation.

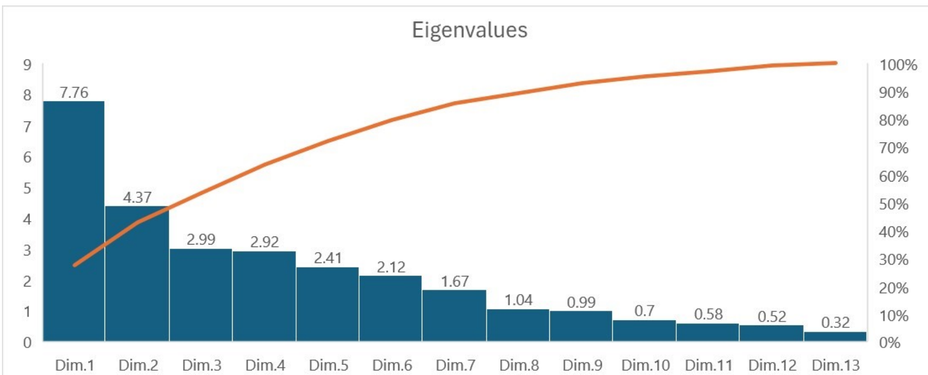

Figure 2.3: Scree plot for eigenvalues in different dimensions.

Table 2.5 shows the contribution scores of each attribute to the six dimensions. These scores help explain what each dimension represents and how it relates to consumer perception of freshness. Dimension 1 is mainly defined by the attribute "Dislike," which has the highest contribution score (4.46). This means Dimension 1 captures negative views of freshness, especially those related to artificial or unwanted qualities. Other important contributors to this dimension are "Artificial" (1.34) and "Clean" (1.05), showing a mix of disliked, artificial qualities and cleanliness. The attributes "Fresh" (0.56) and "Overpowering" (0.74) also contribute to this dimension, further emphasizing its mixed nature of both positive and negative aspects.

Dimension 2 is characterized by attributes such as "Fruity" (3.11) and "Laundry" (2.12), which are both linked to freshness. The high value for "Fruity" in this dimension suggests that Dimension 2 captures positive and familiar aspects of freshness. Dimension 3 is mostly influenced by "Baking" (1.89), which has the highest score for this attribute across all dimensions. Other important attributes in Dimension 3 include "Floral" (1.51), "Outdoor" (1.21), and "Seasonal" (1.62). This suggests that Dimension 3 represents warmth, familiarity, and a connection to nature. Dimension 4 is influenced by "Fruity" (1.07), indicating some positive aspects. However, the attribute "Artificial" (0.68) also contributes, showing a mix of positive and negative perceptions of freshness, possibly indicating complexity in the scents.

Table 2.5: Contribution scores of each attribute to each dimension

Attributes	Dim 1	Dim 2	Dim 3	Dim 4
Artificial	**1.34**	0.49	0.13	0.68
Baking	0.37	0.49	**1.89**	0.01
Clean	**1.05**	0.34	0.21	0.18
Citrus	0.02	0.49	**0.50**	0.11
Dislike	**4.46**	0.03	0.38	0.05
Floral	0.05	0.30	**1.51**	0.19
Fresh	**0.56**	0.14	0.01	0.06
Fruity	0.28	**3.11**	0.02	1.07
Home	0.01	0.01	0.27	0.01
Laundry	0.56	**2.12**	0.00	0.12
Lemon	0.47	0.01	0.12	0.02
Like	0.02	0.01	**0.32**	0.27
Light	0.32	0.01	**0.54**	0.32
Neutral	0.00	0.67	0.00	0.04
Outdoor	0.11	0.00	**1.21**	0.03
Overpowering	**0.74**	0.04	0.70	0.18
Seasonal	0.31	0.02	**1.62**	0.00
Singular	0.42	0.10	0.03	0.15
Sweet	0.09	0.00	0.63	0.37

*Bold scores are the highest eigenvalue for each attribute.

The two-dimensional plots, Figure 2.3, provide a visual representation of how attributes and samples are distributed across these dimensions. In the Dim1 vs. Dim2 plot, attributes such as "Dislike" and "Artificial" are positioned opposite to positive attributes like "Floral," "Citrus," and "Freshness." This contrast reflects a separation between negative and positive perceptions of freshness, with Dimension 1 representing negative attributes and Dimension 2 emphasizing familiar, uplifting qualities. Samples such as "PR_E" are associated with negative attributes like "Dislike" and "Artificial," while samples like "PR_D" are closer to positive descriptors like "Freshness" and "Floral," highlighting this contrast.

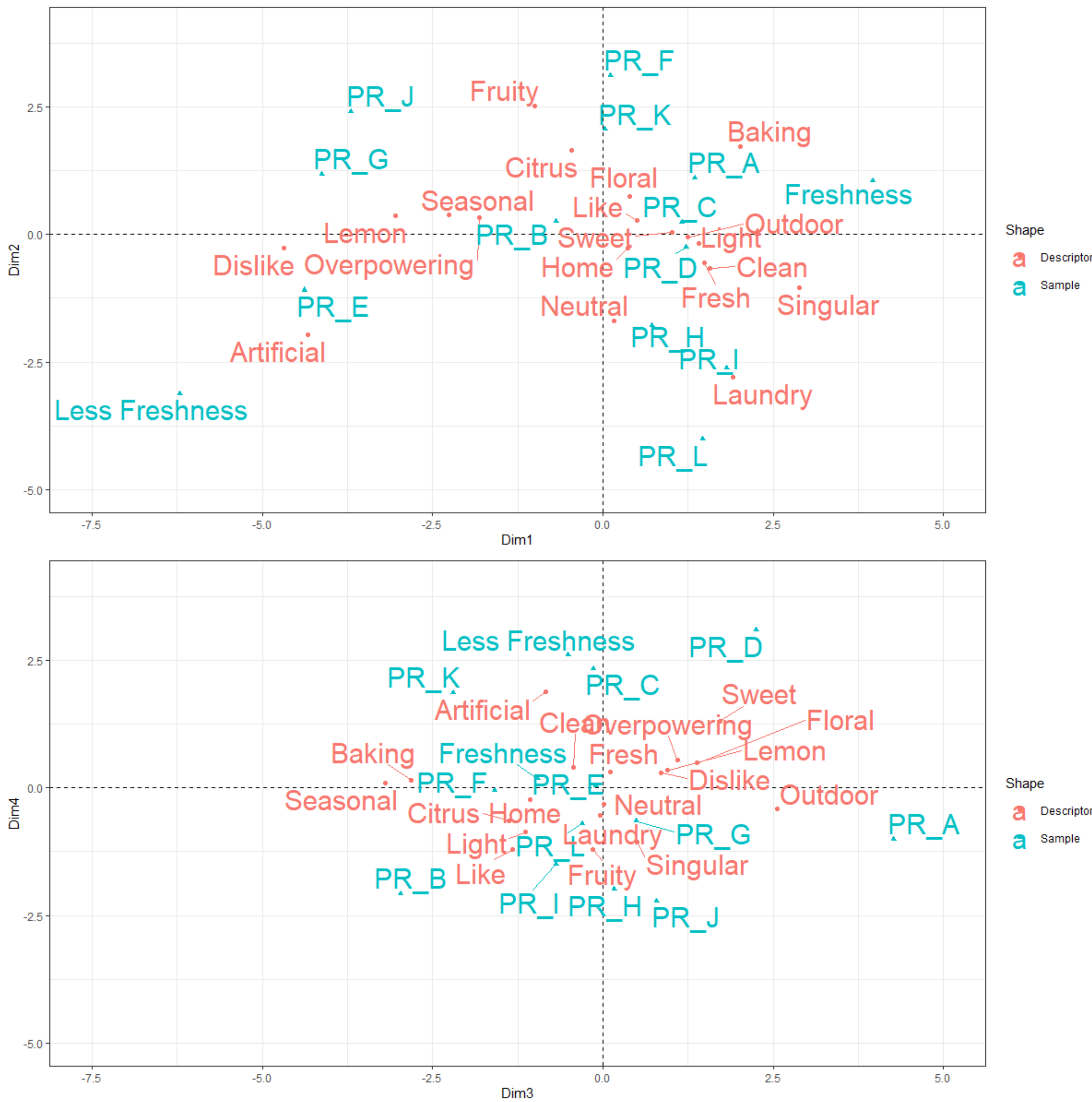

Figure 2.4: Landscape mappings for freshness dimensions and product attributes in multiple factor analysis. (Dim1 vs. Dim2; Dim3 vs. Dim4)

The Dim3 vs. Dim4 plot shows a mix of comforting and intense attributes. "Baking" and "Seasonal" are positioned far from the original point, reflecting associations with warmth and familiarity. At the same time, attributes such as "Overpowering" and "Artificial" are also present, indicating the perception of certain scents as overly intense. Samples in this plot, such as "PR_B" and " PR_F," are located near comforting attributes like "Baking," suggesting a nostalgic quality, whereas other samples align with more intense descriptors, indicating negative connotations.

Upon integrating the table and the plots, it becomes evident that Dimensions 1 and 2 provide the clearest separation between products labeled as "Fresh" and "Less Fresh" that explains 43% of variability. In further dimensions, the overlapping and mixed contributions of attributes such as "Baking," "Overpowering," and "Seasonal" create more ambiguous interpretations, making it difficult to distinctly classify products based on freshness. This complexity suggests that focusing on Dimensions 1 and 2 allows for a more straightforward exploration of freshness, capturing both positive and negative elements in a clearer manner, which is why these dimensions are prioritized for understanding consumer perceptions of freshness.

Figure 2.5 provides the detailed Dim1 vs. Dim2 plot offering insights into how specific products and attributes are perceived by participants regarding freshness. The plot highlights clear divisions between products labeled as "Fresh" and those seen as "Less Fresh," based on consumer-perceived terms, package descriptions, and categorical fragrance group (CFG) descriptors.

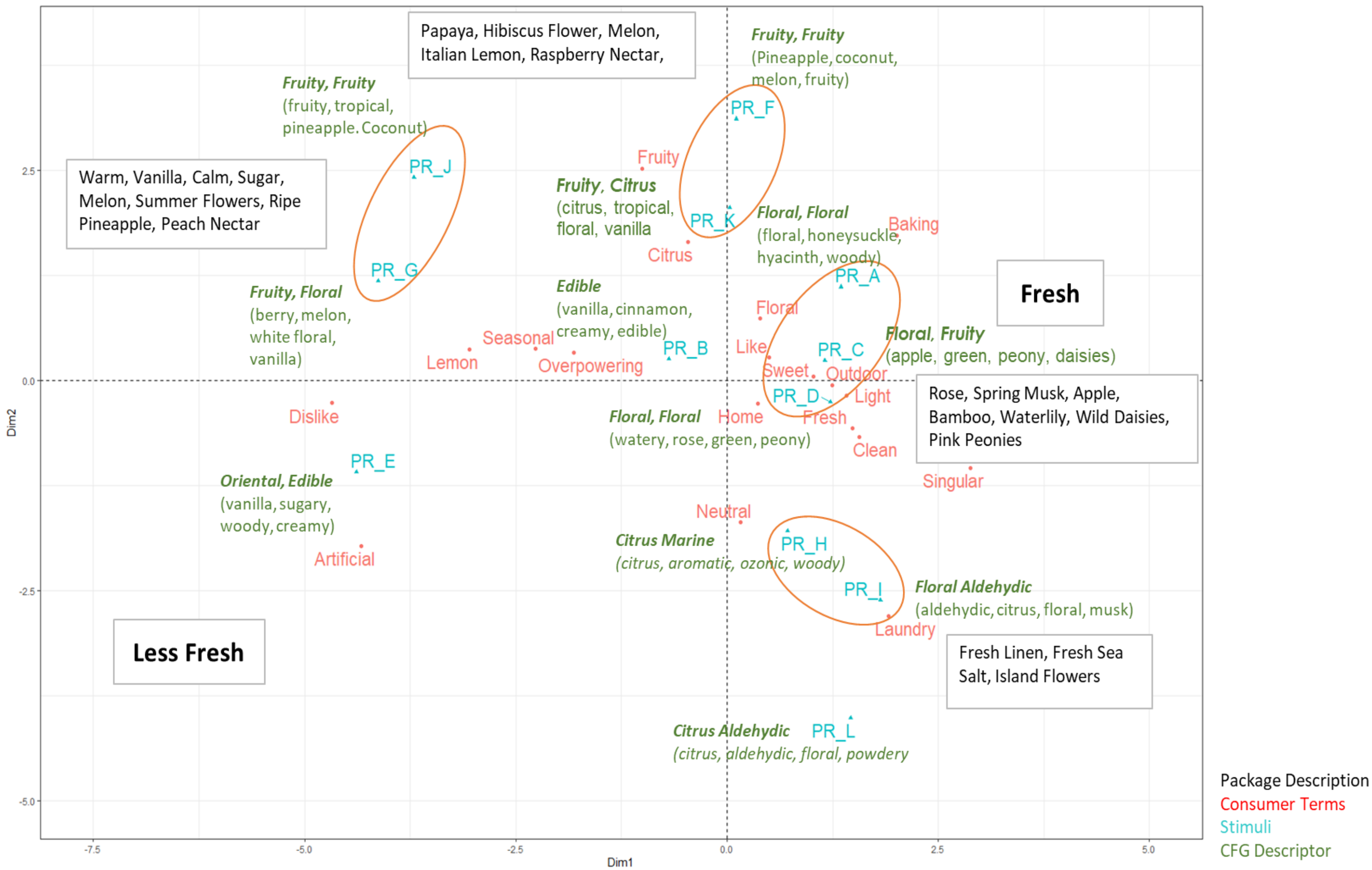

Figure 2.5: Landscape mapping for freshness attributes and product samples in two dimensions

Products perceived as "Fresh" are positioned in the top-right quadrant, aligned with positive attributes such as "Floral," "Citrus," and "Freshness." These attributes represent natural and uplifting qualities. Products such as "PR_C" and "PR_K" are associated with consumer terms (in red) like "Floral" and "Citrus," suggesting they are seen as refreshing. Package descriptions (in black with frames) like "Rose," "Spring Musk," and "Apple" reinforce the freshness imagery, while CFG descriptors (in green) such as "Bamboo," "Wild Daisies," and "Pink Peonies" further support these natural qualities.

Products perceived as "Less Fresh" are located in the bottom-left, associated with negative attributes such as "Artificial," "Dislike," and "Overpowering." Products like "PR_E" and "PR_H" are associated with consumer terms (in red) such as "Artificial," "Vanilla," and "Sugary," which are considered less fresh. The package descriptions (in black with frames) include terms like "Vanilla" and "Woody," and CFG descriptors (in green) such as "Oriental" and "Edible" also contribute to the perception of these scents as less fresh.

The products, such as "PR_J" and "PR_G," are positioned closer to the center, indicating a blend of positive and negative attributes. These products have mixed consumer perceptions, reflecting elements like "Warm," "Vanilla," and "Melon," which can be perceived differently depending on the context. The package descriptions and CFG descriptors for these products also show a mixture of attributes, contributing to their intermediate positioning.

The Dim1 vs. Dim2 plot highlights the complexity of freshness as a concept. Positive freshness is linked to floral, citrus, and fruity elements, while negative freshness is associated with artificial and overpowering characteristics. Consumer-perceived terms, package descriptions, and CFG descriptors all play a role in shaping these perceptions. Products like

"PR_L," with CFG descriptors such as "Fresh Linen," "Fresh Sea Salt," and "Island Flowers," effectively evoke freshness by emphasizing natural qualities.

Graphical model results

The network plot, Figure 2.6 shows the relationships among sensory descriptors used by participants to describe their perceptions of freshness. At the center of the plot are attributes like "Light," "Fruity," "Fresh," "Clean," and "Floral," which have many connections to other sensory descriptors. These attributes express how participants think about freshness, as also seen in the MFA results, where these terms had high contribution scores. These core terms form the main components of the freshness concept that participants recognized and used most often.

Around these central descriptors are other terms like "Herbal," "Baking," and "Artificial," which have fewer connections but still play a role in how participants perceive freshness. These secondary terms add more detail to the perception of freshness, extending the main attributes identified in the MFA results. For example, "Artificial" had a strong influence in Dimension 1, matching its placement in the network as a term linked to negative aspects of freshness. The MFA results showed that Dimensions 1 and 2 clearly separated "Fresh" and "Less Fresh" products, while this network plot shows how individual descriptors contribute to these perceptions.

The decomposition of the network relationships adds more detail about how the attributes are connected. Figure 2.7(a) shows two types of relationships: "Conditional Dependent" and "Conditional Independent." In the "Conditional Dependent" network, attributes such as "Fresh," "Light," and "Clean" are connected to many other descriptors, showing how these key attributes are closely linked to others. This matches the MFA results, where attributes such as "Fresh" and "Clean" were important in explaining the differences across dimensions. On the other hand, the

"Conditional Independent" network shows attributes such as "Woody," "Vanilla," and "Lavender" that are more distinct and not strongly connected to the core freshness concept.

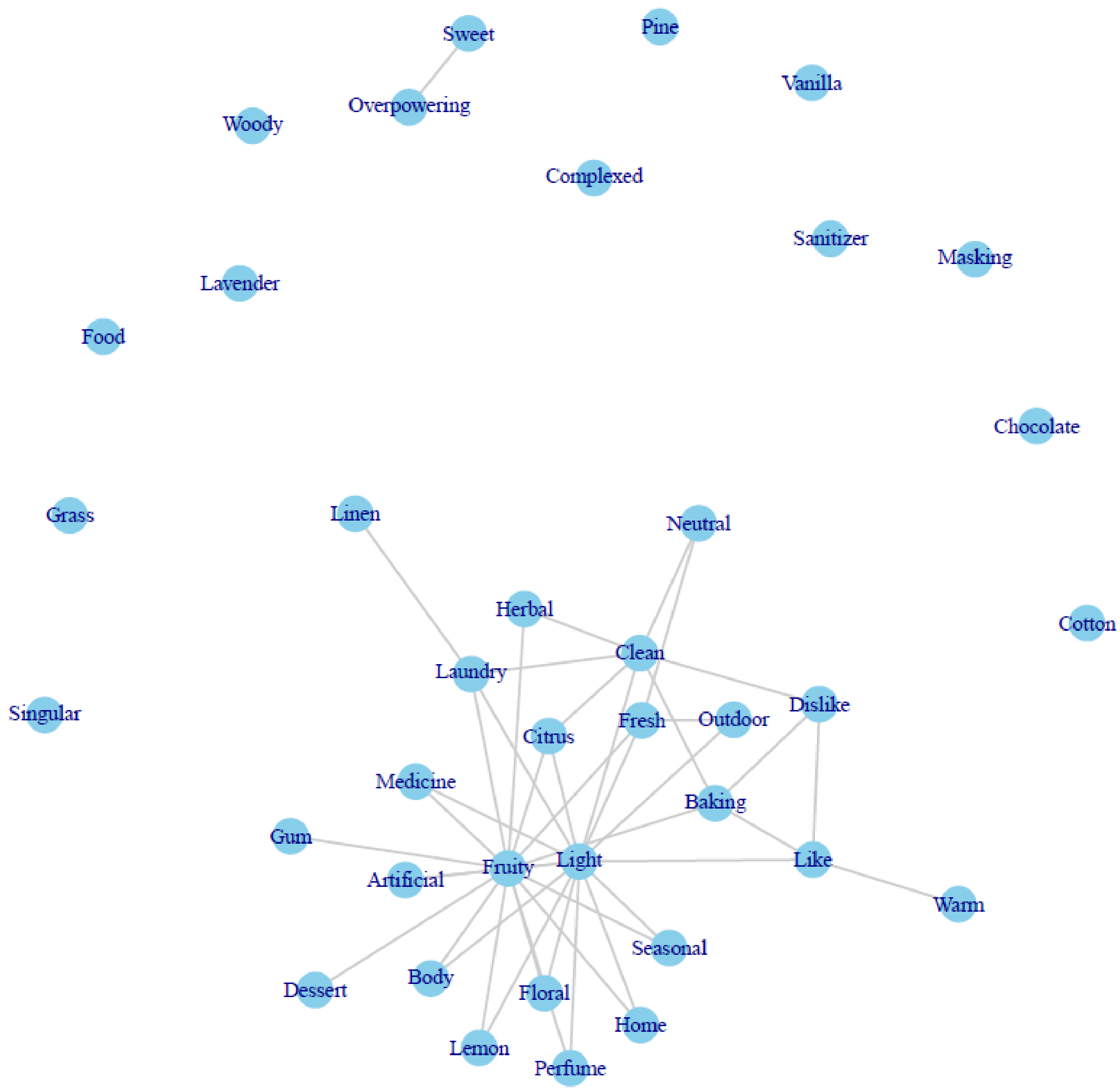

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Figure 2.6: Network relationships among attributes contributing to freshness perception

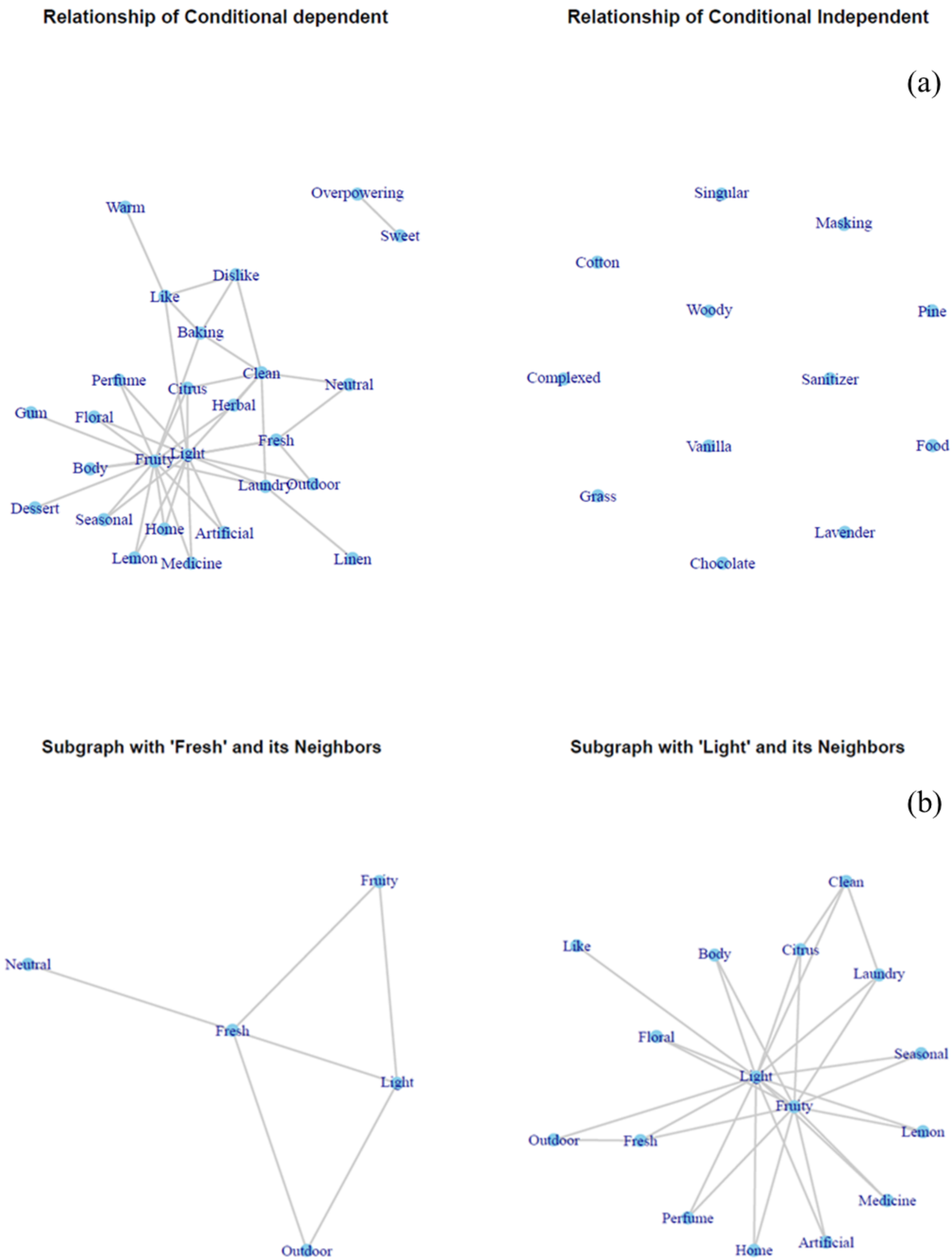

Figure 2.7: Decomposition of network relationships among freshness attributes, showing conditional dependencies and independences (a) and subgraphs of key attributes 'Fresh' and 'Light' (b)

Figure 2.7(b) shows subgraphs centered around "Fresh" and "Light." The subgraph for "Fresh" shows connections with "Neutral," "Light," and "Outdoor," suggesting that "Fresh" is linked to subtle and natural qualities. This aligns with Dimension 2 of the MFA, where "Fresh" was connected to positive attributes such as "Fruity" and "Laundry," indicating a natural and pleasant sense of freshness. The subgraph for "Light" is more complex, showing many connections to descriptors such as "Clean," "Citrus," "Floral," and "Fruity." This suggests that "Light" is a versatile attribute, contributing to different positive qualities, which is consistent with its high contribution scores in multiple dimensions in the MFA. This means that whatever the character of the attribute is, it has to be light and not overpowering to be perceived as “fresh”.

By integrating the MFA results with the network analysis, we get to know how participants perceive freshness. The MFA showed that Dimensions 1 and 2 were the most effective at separating "Fresh" and "Less Fresh" products, focusing on both positive (e.g., "Fruity," "Clean") and negative (e.g., "Dislike," "Artificial") elements. The network plot adds to this by showing how these descriptors are connected, with central attributes such as "Fresh" and "Light" acting as key points in the network, while others add more detail or stand alone. Attributes such as "Overpowering" and "Artificial," which are in the MFA's Dimension 1, are shown in the network as linked to the core freshness nodes but also contributing to the negative side of freshness.

The network’s architecture—its central nodes, secondary descriptors, and peripheral terms—reflects the complex nature of sensory perception. The visualization of these relationships offers a prelude to the rich qualitative data explored in the interviews, setting the stage for a deeper understanding of how personal experiences, emotional responses, and contextual factors inform and shape the consumer’s sensory world. This network plot is foundational for further discussion, providing a structured visualization of the data that will be further illuminated by the personal narratives and detailed insights from the focus group interviews to follow. We have summarized the above discussed relationship in Table 2.6 below.

Table 2.6: Term and its category related to freshness

	Category	Terms
Core Freshness Attributes	Freshness Indicators	Fresh, Light, Clean, Citrus, Floral
	Natural Freshness	Fruity, Outdoor, Herbal, Lemon
	Subtle Freshness	Neutral, Seasonal, Subtle
Freshness Associated Attributes	Mixed Freshness Elements	Baking, Sweet, Overpowering, Artificial, Medicine
	Comfort and Familiarity	Cozy, Home, Laundry
Unique Freshness Attributes	Distinct Freshness Terms	Pine, Woody, Lavender, Vanilla, Grass, Cotton, Complexed
	Negative Freshness Aspects	Artificial

After mapping discussion

After the sensory mapping exercise, focus group participants discussed why they rated the scents the way they did. The mapping showed that participants often linked light scents to freshness. They described these scents as "light" and "not overpowering," suggesting that people see freshness in subtle and mild scents. This shows that a gentle scent is important when people think of freshness.

The discussion also showed that participants preferred natural scents over artificial ones. They liked aromas that felt organic and real. One participant described the difference between "natural smelling" and "kind of artificial." This shows that people see freshness as linked to natural qualities. They can tell the difference between scents that feel natural and those that are synthetic. For them, natural scents are a sign of freshness. Participants also talked about how certain scents made them feel. Some scents gave them feelings of comfort or relaxation. One participant said that a scent made them want to "cozy up and read a book." This shows that freshness is not just about the smell, it also affects how people feel. Some scents were noted for keeping a place fresh, such as eucalyptus and peppermint in a classroom. This shows that freshness has both an emotional side and a practical side. Overall, the discussion painted a picture of freshness that is delicate, natural, emotionally meaningful, and effective. These qualities together make up how consumers understand freshness.

Main topics in Air-Care E-commerce comment reviews

After multiple iterations to determine the optimal parameters for the topic model, a Latent Dirichlet Allocation (LDA) model with 6 topics was chosen to best represent the dataset related to freshness perception. The LDA analysis captured distinct themes based on participants' discussions, with each topic reflecting an important aspect of their overall perception of freshness. The most important tokens (top 15) for each topic are shown in the plots below (Figure 2.8), providing insights into different aspects of freshness perception as experienced by consumers.

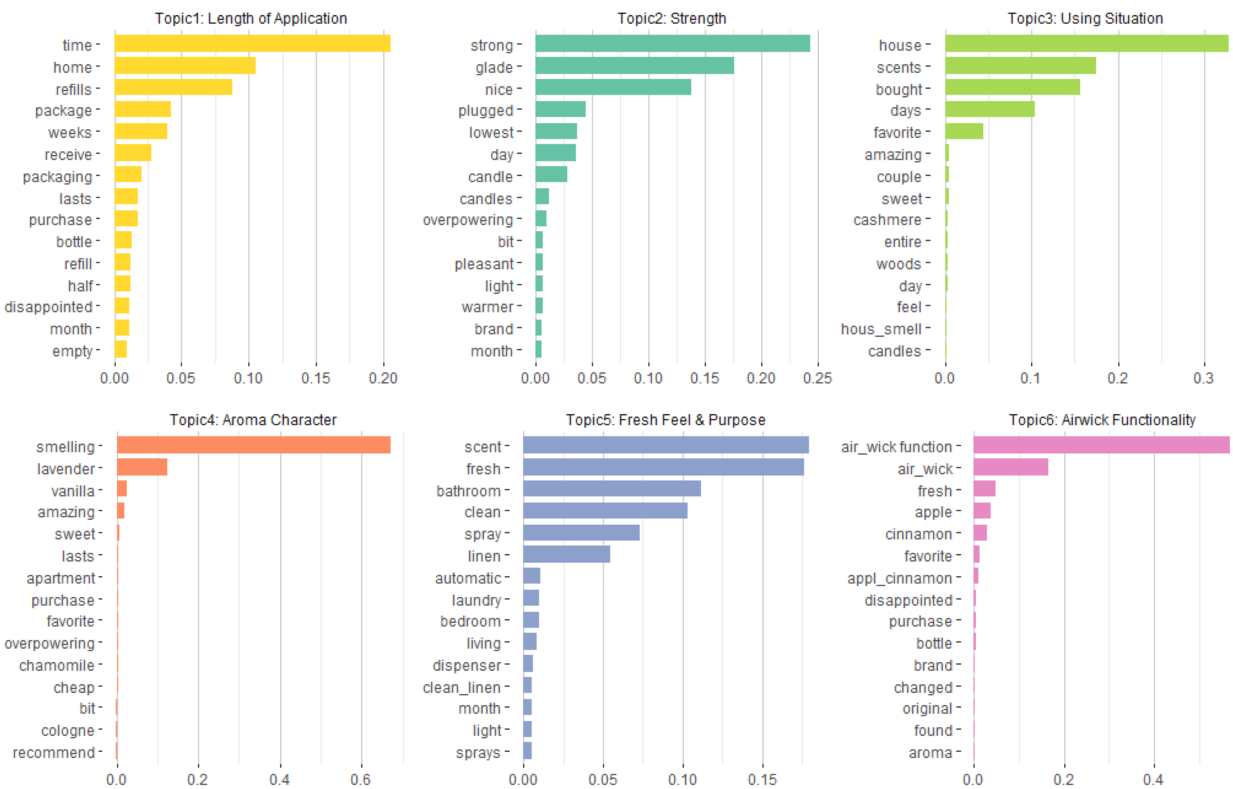

Figure 2.8. Six main topics identified from E-commerce comments of air-care by LDA topic modeling

LDA analysis identified six main themes related to freshness perception: the duration of application, scent strength, situational usage, aroma characteristics, the purpose and feel of freshness, and brand-specific perceptions. These topics provide a nuanced understanding of what aspects of freshness are important to consumers, including both sensory attributes like aroma and functional aspects like duration and usage context.

The six topics identified from the LDA model capture different aspects of the freshness experience. Topic 1: Length to Apply centers around time-related terms such as "time," "home," "weeks," and "lasts," suggesting that the duration of freshness and how often products need to be refilled are important factors for consumers. Topic 2: Strength emphasizes terms such as "strong," "glade," and "plugged," reflecting the value consumers place on the intensity of a scent, with both positive and negative connotations of strength. Topic 3: Using Situation includes words like "house," "scents," and "favorite," pointing to specific contexts in which scents are used, such as home environments and particular occasions.

Topic 4: Aroma Character describes the sensory quality of the scent, with terms such as "lavender," "vanilla," and "sweet" indicating a focus on the nature of the aroma—whether it is floral, herbal, or sweet. Topic 5: Fresh Feel & Purpose features terms such as "scent," "bathroom," and "linen," representing the functional role of freshness, including uses in specific rooms like the bathroom and for items like laundry. Topic 6: Fresh Perception highlights consumer brand preferences and emotional connections, with terms like "Airwick," "fresh," and "apple" emphasizing the importance of specific brands and products in creating a positive freshness experience.

These findings are consistent with insights from our focus group study, where participants similarly emphasized the importance of scent strength, duration, and specific situational uses when describing freshness. In both cases, terms related to clean, natural, and subtle scents were commonly associated with positive freshness experiences. Additionally, participants highlighted the value of certain brands and product types in creating a preferred freshness effect, suggesting a consistent consumer preference for particular qualities and associations in both qualitative discussions and the topic model results.

The learnings used to build the concept of freshness were gathered from both the focus group study and E-commerce comment review. These learnings were integrated and summarized in Table 2.7.

Table 2.7: Dimensions and terms related to freshness via focus group and E-commerce comment review

Dimensions	Terms	Key Insights
Emotional and Psychological Impact	Nostalgic memories, positive emotions, comfort, relaxation, rejuvenation, mood influence, calmness, happiness	Freshness can evoke emotional factors related to personal memories and positive feelings.
Environmental Elements	Cleanliness, safety, air quality, quality of life, seasonal influence, outdoor scent, cozy atmosphere.	Freshness is associated with an improved environment, contributing to air quality, safety, and overall wellbeing, including seasonal aspects.
Physical Sensation and Sensory Character	Clean scents, floral scents, fruity scents, crispness, lightness.	Sensory character dimensions indicate specific scent profiles related to freshness, including clean, floral, or fruity aromas.
Product Context	Seasonal influence, usage context, time to apply, long-lasting freshness, strength, complexity of scent	Freshness is influenced by the practical context of product use.
Functional Role	Masking unwanted aromas, clean scent, purpose of use	Air Care products are valued for their functional roles, such as masking odors and providing a clean, “fresh” scent.

Discussion

This study helped us understand how people think about freshness by using multiple approaches, including qualitative insights, graphical models, multiple factor analysis, and comment reviews. The analysis reveals important insights into what makes a scent feel fresh to consumers. In focus group discussions, participants often mentioned that they prefer scents that are not too strong but are more natural and light. This preference aligns with the findings in our graphical model, where "Fresh" and "Light" are key nodes linked to other positive qualities like "Outdoor." This connection shows that consumers often associate freshness with an outdoor, airy feeling. Even though “crisp” was not part of the graphical models because it was not brought up during the mapping exercise, it was brought up several times during the discussion. Based on consumer comments, “Crispness” was an important descriptor of freshness, and it was related to attributes such as cleanliness, sharpness, and clarity. Consumers often associate crispness with the perception of a fresh environment, which includes a feeling of renewed air quality, a bright and invigorating atmosphere, and the absence of heaviness or staleness. It was also linked to scents that are light and uplifting, contributing to a sense of vitality and rejuvenation.

The graphical model also highlighted how "Light" is connected to attributes such as "Citrus," "Floral," and "Clean." These are qualities that participants related to light and subtle scents. The use of these light scents, such as eucalyptus and peppermint, was also mentioned by participants for keeping a classroom environment feeling fresh. This shows that lightness in a scent is not just about the smell—it also gives a sense of cleanliness and order. These connections in the graphical model match what participants shared in the focus groups, proving that this method is helpful in capturing the complex ways people perceive freshness. Using a graphical model alongside multiple factor analysis helped us better understand these patterns. It did not replace traditional methods but added another way to look at the data, helping to find clear relationships between attributes. This approach made it easier to see which aspects of freshness are most important and how they are connected. By integrating these models, we gained a deeper understanding of how consumers naturally and emotionally experience freshness.

The topic modeling approach provided an understanding of perspectives from users' experiences. Many emotion terms such as "amazing," "pleasant," "nice," "favorite," etc., were associated with terms related to "day," "length," "time," etc., and terms related to location/environment such as "home," "bedroom," "living room," and "kitchen." These associations suggest that consumers connect freshness with specific positive experiences throughout the day, often linked to their personal living spaces. For instance, a fresh scent in the bedroom might be associated with relaxation and comfort, whereas in the bathroom, freshness might signify cleanliness. The connection between emotions, time, and place also highlights the role of freshness in creating a positive and welcoming environment in different settings. This finding shows the importance of considering both temporal and spatial elements when understanding how consumers experience and describe freshness. For example, a scent that evokes freshness in the morning may be different from one preferred in the evening, depending on the desired atmosphere. The use of topic modeling alongside focus group adds depth to our understanding of how freshness may be perceived in various contexts and how it contributes to consumers' emotional wellbeing.

Limitations and future research

One limitation of this study is that it focuses on a small set of air freshener scents and environments. Future studies could look at more types of scents, to see if they lead to similar results. Although this study was controlled in environments to have consistent results, it did not fully explore in real conditions and how factors such as room size, ventilation, or other aromas affect freshness. Future research could include these details to get a better understanding of how freshness works in different spaces. It would also be useful to study things like temperature or humidity, which might change how scents are perceived. This would help improve product development for a wider range of situations.

Another opportunity is to look at how individual differences affect freshness. This study did not explore personal factors, such as cultural background or scent preferences. Future research could focus on how people from different groups experience freshness. This could help in designing products that appeal to specific groups. Also, new techniques like machine learning could help to find more complex patterns in consumer preferences. Lastly, the current methods used in this study require advanced programming, which can be a barrier. Making these tools more user-friendly would help more researchers and companies apply these methods to create better products that meet consumer needs.

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Conclusion

By using focus group and E-commerce comment review, we identified five key dimensions of freshness. (1) Emotional and psychological factors are important with specific features including "nostalgic memories," "positive emotions," "comfort," and "happiness" showing that freshness evokes personal memories and positive feelings. (2) Environmental elements such as "cleanliness," "safety," "air quality," and "cozy atmosphere" are linked to freshness, showing how people see it as improving their living environment and overall wellbeing, including certain seasonal aspects as well. (3) Physical sensations and sensory character are also crucial, with "clean scents," "floral scents," "fruity/citrus scents," "crispness," and "lightness" contributing to how freshness is experienced. (4) Product context, such as "usage time," "long-lasting freshness," and "complexity of scent," affects how people perceive freshness in different situations. Finally, (5) the functional role of freshness is important with products that "mask unwanted odors" or provide a "long lasting," "clean scent" seen as valuable because they serve a practical purpose.

It will be important to further explore each of these concepts and determine which of these are specifically related to freshness, and which are more a feature of home scents in general. Validating these concepts as well as their application in the connect of product usage will be important to further clarify, which dimensions are most important at identifying and explaining the role of freshness in consumer perception of fragrances in home-care products.

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Chapter 3 - Development and Validation of the Air Care Freshness Concept

Introduction

The concept of freshness is not only central to food but also plays an important role in the realm of air care products, personal care, perfumes, and other non-food categories. From the consumers' point of view, freshness is a critical attribute in assessing the overall quality and effectiveness of these products (Farruggia et al., 2016; Tsiros and Heilman, 2005; Fenko et al., 2009).

In the context of air care and fragrances, freshness often relates to the sensory and psychological impact that scents can have on an environment or individual. Unlike food products, where freshness is tied to attributes related to taste and texture, freshness of nonfood categories such as air care and perfume primarily, relies on olfactory properties (Saba et al., 2018). Scents that evoke a sense of cleanliness, renewal, and wellbeing are often associated with freshness in these categories, while other elements such as the longevity of the scent or its ability to mask unpleasant odors are also considered important (Peneau et al., 2006).

Recent innovations in the perfume industry have introduced a multisensory approach to enhance the perception of freshness. Research has demonstrated that integrating auditory elements, such as brand-aligned soundtracks, can significantly influence how consumers perceive freshness in fragrances (Rodriguez et al., 2024; Bouteille et al., 2013). By modulating the olfactory experience with sound, consumers reported enhanced freshness attributes such as coldness, lightness, and even the color blue. This multisensory strategy underscores the evolving complexity of freshness perception in non-food categories, where visual, auditory, and olfactory elements converge to create a more immersive experience.

In addition to sensory innovation, the olfactory descriptors of freshness continue to evolve. The freshness category in perfumery comprises subfamilies such as citrus, green, water, and fruity, which are perceived as refreshing, while warm, oriental, and powdery notes are considered opposite (Thiboud, 1991). Fresh scents are often associated with top notes due to their high volatility, quickly evaporating to create an initial burst of freshness that is contrasted with more long-lasting, heavy base notes such as musk and animalic scents (Thiboud, 1991). However, the volatility of these fresh top notes poses a challenge for perfumers, as it can affect how long the perception of freshness lasts during use. Despite this, light fragrances remain highly sought after in the air care and perfume industry for their ability to evoke cleanliness, renewal, and wellbeing in consumers' environments.

Similar to food, the perception of freshness in air care and fragrance products can be influenced by both sensory and non-sensory factors (Cardello et al., 2012; Dinnella et al., 2014; Spinelli et al., 2014). Sensory attributes such as fragrance intensity, crispness, and clarity often dominate consumer evaluations, but non-sensory elements such as packaging, product claims, and branding can also impact perceptions of freshness. These attributes play an essential role in shaping consumer behavior, particularly in how they choose and use products designed to refresh their living spaces or personal environments (Peneau et al., 2009).

Research on air care products has highlighted the importance of situational factors, such as the environment in which the scent is experienced, in shaping consumer perceptions of freshness. For instance, a scent that may seem fresh and invigorating in a living room might be perceived differently in a bedroom or bathroom, where different freshness cues are expected (Grunert et al., 2000). Moreover, factors such as seasonality and personal preference often influence which fragrance notes are associated with freshness, whether it is a light floral scent for spring, or a cool, crisp scent for winter.

Considering all of this, the objective of this study was to gain insights into consumers' perceptions of freshness within the air-care and fragrance categories by examining both sensory and non-sensory attributes. This paper focuses on how consumers interpret freshness in different environments, such as homes or workspaces, and explores how this perception may vary based on the specific product type. The overall aim of this research is to explore the underlying factors that contribute to the perception of freshness in air-care products, addressing two main objectives: 1) to develop a list of the key statements addressing both sensory and non-sensory cues associated with freshness perception in air care products, based on previous research; and 2) to validate these statements from a conceptual perspective, to further understand the degree to which these statements are relevant and important to describe freshness in air care products.

Methods

The statement development process for defining and refining the concept of freshness in air-care products is outlined in Table 3.1. The process began with the construction of a freshness concept definition, which involved three focus group discussions, qualitative analysis of the transcripts, and a literature review integrated with E-commerce comment analysis to define the freshness concept and identify its sub-dimensions. This was covered in Chapter 2. Based on this, 33 statements were generated based on the definitions and sub-dimensions explored earlier. The scale purification and statement refinement stage involved an online survey of N=451 routine air-care product users, where the statements underwent assessments for importance and reliability to accurately describe the concept of freshness, followed by exploratory factor analysis and statement reduction.

Table 3.1 : Statement development process

Stage	Description
Construct Freshness Definition (Chapter 2)	Three focus group discussions Qualitative analysis of focus group transcripts to clarify the freshness conception Literature review and analysis of E-commerce comments to define the freshness concept and its sub-dimensions
Statements Generation and Expert Review	Generation of 33 statements based on definitions and sub-dimensions. Rephrasing of statements based on internal feedback
Scale Purification and Statement Refinement	Survey of N=451 air-care product users Statements informative assessment Statements effective assessment Exploratory factor analysis Statements' reliability assessment Statements differentiability assessment Statement refinement and reduction
Finalization and validation of the final list statements	Survey of 154 air-care product users Confirmatory factor analysis Reliability validity Determine if the final list of statements uniformly describes the freshness concept

Raw concept and statements for survey

The three focus group discussions with a total of 20 routine air-care products users, and the E-commerce comment reviews explored in chapter 2 generated the information below:

- **Scent Character:** Fresh scents are clean scents related to pleasantness at home. They can be characterized by fruity, floral, or outdoor scents, and maintain good air quality within the user's living space. Consumers prefer scents that are simple yet can be complex, needing to be light and crisp. Fresh scents need to mask unwanted aromas. A fresh scent may create a tingling sensation in the nose.
- **Productivity, Stress Relief, and Wellbeing:** An environment with a fresh scent helps reduce stress and can positively impact productivity and focus. Fresh scents evoke a sense of wellbeing, making consumers feel rejuvenated and improving their overall quality of life. Consumers associate freshness with positive emotions, as fresh scents can influence their mood by bringing a sense of happiness and calmness. A fresh scent contributes to a sense of safety within the living space, creating a comfortable and relaxing environment. These scents contribute to emotional and psychological wellbeing, going beyond just the physical aroma.
- **Renewal and Rejuvenation:** Fresh scents are connected to a sense of renewal and rejuvenation in consumers' living spaces. Fresh scents make consumers feel refreshed and can evoke positive emotions from past experiences, even bringing nostalgic memories. Consumers' choice of fresh scents is influenced by the time of year, as different scents can evoke a sense of excitement and wellbeing associated with the seasons.

The survey needs to include specific statements designed to capture the concept of freshness as identified above. The statements are required to be structured clearly and concisely, facilitating straightforward responses from participants. Each question aims to probe a specific aspect of freshness, ensuring comprehensive coverage of the concept. With this in mind, 33 statements were constructed to fully account for the multi-dimensional concept of freshness and was tested in an online survey (Table 3.2).

Table 3.2 Statements generated to explore the multi-dimensional concept of freshness

Item #	Statements
Item 1	A fresh scent can evoke nostalgic memories
Item 2	A fresh scent can evoke positive emotions from past experiences
Item 3	A fresh scent contributes to a sense of safety within my living space
Item 4	A fresh scent creates a tingling sensation in my nose
Item 5	A fresh scent gives a feeling of cleanliness in my home
Item 6	A fresh scent maintains good air quality within my living space
Item 7	A fresh scent makes me feel rejuvenated
Item 8	An environment with a fresh scent can improve my overall quality of life
Item 9	An environment with a fresh scent can positively impact my focus
Item 10	An environment with a fresh scent can positively impact my productivity
Item 11	An environment with a fresh scent helps reduce stress
Item 12	An environment with a fresh scent is connected to a sense of renewal
Item 13	Fresh scents are clean scents
Item 14	Fresh scents are floral scents
Item 15	Fresh scents are fruity scents
Item 16	Fresh scents are outdoor scents
Item 17	Fresh scents bring a sense of comfort to my living space
Item 18	Fresh scents bring a sense of relaxation to my living space
Item 19	Fresh scents can influence my mood
Item 20	Fresh scents create a cozy atmosphere in my living space
Item 21	Fresh scents evoke a sense of calmness
Item 22	Fresh scents evoke a sense of excitement
Item 23	Fresh scents evoke a sense of happiness
Item 24	Fresh scents evoke a sense of well-being
Item 25	Fresh scents need to be complex
Item 26	Fresh scents need to be crisp
Item 27	Fresh scents need to be light
Item 28	Fresh scents need to be simple
Item 29	Fresh scents need to be strong
Item 30	Fresh scents need to mask unwanted aromas
Item 31	I associate freshness with positive emotions
Item 32	My choice of fresh scents is influenced by the time of year
Item 33	Scents for my home have to provide a long-lasting fresh scent

Online survey design

The survey in this study was conducted using the online platform, Qualtrics, which facilitated the creation, distribution, and efficient collection of responses. The Qualtrics platform provides a streamlined approach that makes data collection accessible to a broad range of participants. This study consisted of N=451 participants from diverse demographics, ensuring variability in age, gender, and familiarity with household product composition. The details of the demographic construct of participants can be found in Table 3.3.

A 7-point Likert scale was used to measure agreement with various statements about freshness, ranging from "strongly disagree" (1) to "strongly agree" (7). Additionally, a 5-point importance scale assessed the significance of these statements in the context of air care products. The scale ranged from "very unimportant" (1) to "very important "5." A decision matrix was developed to determine the next steps based on the results (Figure 3.1). If a statement was agreed and deemed important by 80% or more of participants, then it was kept. If there was conflicting responses between agreement and importance, then the statement was flagged for evaluation and possible removal. If a statement was disagreed with and deemed unimportant by more than 20% of participants, then it would be automatically eliminated.

Statements	IMPORTANT	UNIMPORTANT (>20%)
AGREE	KEEP: Appropriate statement to measure Freshness – KEEP	EXPLORE: Statement may need to be reworded or eliminated
DISAGREE (>20%)	EXPLORE: Statement may need to be reworded or eliminated	ELIMINATE: Statement is not appropriate to measure freshness

Figure 3.1. Decision matrix for next steps based on survey results

Table 3.3: Demographic of online survey participants (N = 451)

Gender	Percentage
Male	27%
Female	73%
Age	%
18-25 Years	18%
26-36 Years	32%
36-45 Years	27%
46-55 Years	23%
Purchasing Behavior	%
I do all or most of the shopping for my household	73%
I share the responsibility equally with someone else	27%
Household Product Use	%
Air care/fragrances	100% (Q)
Cleaning/disinfectant	98%
LED lightbulbs	69%
Fan/humidifier	62%
Carpet cleaners	49%
Cat litter	40%
Security cameras	34%
Air Care Product Use	%
Aerosol air fresheners	80%
Scented candles	79%
Plug-in scented oils	64%
Aromatherapy diffusers	30%
Battery powered automatic sprays	25%
Slow-release gels	23%
Reed diffusers	10%
Brands of Product	%
Febreze	79%
Air Wick	68%
Glade	67%
Bath & Body Works	48%
Yankee Candle	34%
Renuzit	13%
Method	6%
Store Brand	4%
Other Brand	2%

(Q): Qualification Mandatory, participants had to be users of air care scents

Data collection

Data collection was carried out over three weeks to allow ample time for responses. The online survey link was distributed via email and social media channels to reach a broad audience. Reminders were sent periodically to maximize participation rates and ensure a robust dataset.

Validation

After the first round of validation of the statements, where the original list went through a process of review and modification as deemed necessary based on the results, we conducted a confirmatory study with a separate group of participants to validate the final list of statements. An additional test was conducted with N=154 participants recruited in the Kansas City area by using same the same criteria. This validity test refers to the extent to which the scale accurately measures the concept it is intended to assess, ensuring that the results are meaningful and reliable. Participants were screened using a similar screener as in the previous test. Confirmatory Factor Analysis (CFA) was conducted. Multiple model fit indices were employed to evaluate the adequacy of the measurement model, including chi-square ($\chi 2$) goodness of fit, normed chi-square (CMIN/df < 3), root-mean-square error of approximation (RMSEA < 0.08), standardized root-mean-square residual (SRMR < 0.1), comparative fit index (CFI > 0.90), goodness-offit index (GFI > 0.90), incremental fit index (IFI > 0.90), and Tucker–Lewis index (TLI > 0.90), following the guidelines of Hooper et al. (2008), Qureshi et al. (2022) and Schreiber et al. (2006.

Results and Analysis

Test for matching responses

This means that responses to agreement questions (agree or disagree) should correspond with responses to importance questions (important or not important), as well as with the neutral point. If the two datasets do not match significantly, the statement may not be suitable for inclusion in the scale and will require further evaluation. This mismatch may suggest that participants may not fully understand the statement, or that the data quality is insufficient, possibly because participants made random selections without reading the statement carefully. This would be especially concerning in a scenario where a respondent scores a statement as important to represent freshness, but at the same time, disagrees that it is relevant for freshness, that would be a red flag. A scenario where a respondent agrees that the statement is relevant to describe freshness but also thinks it is not as important is possible.

In this study, the Cochran-Mantel-Haenszel (CMH) test (Wittes and Wallenstein 1987; Coenen et al., 2021) is used to evaluate the association between categories in the 7-point Agreement Likert scale dataset and the 5-point Importance Likert scale dataset across multiple strata. The data include three categories: H (high), representing agreement in the 7-point scale from value 5 to 7 (somewhat agree to strongly agree) matching importance on the 5-point scale from 4 to 5 (important or very important); M (medium), representing the neutral point, value 4 (neither agree nor disagree) matching the corresponding neutral point, value 3, in the Importance scale (neither important nor unimportant); and L (low) value from 1 to 3, representing disagreement in the 7-point scale (somewhat disagree to strongly disagree) matching unimportance in the 5-point scale, from 1 to 2 (unimportant to very unimportant). The aim is to assess whether the matches between the two datasets are statistically different from the nonmatch across the H, M, and L categories.

To conduct the CMH test, the data was organized into stratified $2 \times 2 \times 3$ contingency tables, with each stratum representing one of the three importance's categories (H, M, L). For each stratum, a 2×2 table is constructed where the rows represent whether the results from the

Agreement dataset match the Importance dataset (HH, LH), and the columns represent the predicted categories in the Agreement dataset (LH, LL). This setup allows us to evaluate how well the Agreement dataset predictions align with the Importance categories within each stratum. The CMH test is then applied to pool the data across strata and assess the overall association between the predicted and true categories. The results provide a robust method for determining whether the matches are statistically different from the non-matches and whether these differences are consistent across the H, M, and L categories, controlling for potential differences in the strata distributions.

The CMH test results (Table 3.4) indicate that for all statements, the overall matches between the Agreement and Importance datasets are statistically significant, with p-values below 0.01. This demonstrates a strong association between the two datasets across all strata, confirming that the matches are significantly different from the non-matches. Looking at the individual chi-square results for the High, Medium, and Low categories, many statements exhibit highly significant matches across all categories, with p-values below 0.001, indicating strong consistency in the Agreement-Importance match. However, a few statements (Item 1, Item 2, Item 5, Item 7, Item 10, Item 17, Item 20, Item 21, Item 23, Item 31, and Item 33) show non-significant matches in the Low category, with p-values greater than 0.05, suggesting weaker alignment between the datasets in this category. Despite this, their overall CMH results remain significant, indicating that, when aggregated across strata, the matches are still statistically distinct from the non-matches. The consistent significance across the High and Medium categories for all statements underscores the robustness of the findings for those categories.

Table 3.4 Detailed results of Chi-Square and CMH tests across levels (High, Medium, Low) with effectiveness scores from agreement and importance datasets

	Statement	Individual Chi-Square Test			CMH Overall	Effective Results		
		High p-value	Medium p-value	Low p-value		Effect Average	Effect Agree	Effect Important
Item 1	A fresh scent can evoke nostalgic memories	<0.001	<0.001	2.41E-01	<0.001	0.61	0.64	0.57
Item 2	A fresh scent can evoke positive emotions from past experiences	<0.001	<0.001	6.51E-01	<0.001	0.64	0.67	0.60
Item 3	A fresh scent contributes to a sense of safety within my living space	<0.001	<0.001	7.12E-03	<0.001	0.62	0.62	0.62
Item 4	A fresh scent creates a tingling sensation in my nose	<0.001	<0.001	<0.001	<0.001	0.29	0.30	0.28
Item 5	A fresh scent gives a feeling of cleanliness in my home	<0.001	<0.001	8.30E-01	<0.001	0.89	0.90	0.88
Item 6	A fresh scent maintains good air quality within my living space	<0.001	<0.001	1.68E-02	<0.001	0.74	0.73	0.74
Item 7	A fresh scent makes me feel rejuvenated	<0.001	<0.001	1.04E-01	<0.001	0.76	0.78	0.73
Item 8	An environment with a fresh scent can improve my overall quality of life	<0.001	<0.001	<0.001	<0.001	0.73	0.73	0.73
Item 9	An environment with a fresh scent can positively impact my focus	<0.001	<0.001	<0.001	<0.001	0.76	0.78	0.74
Item 10	An environment with a fresh scent can positively impact my productivity	<0.001	<0.001	3.26E-01	<0.001	0.79	0.80	0.77
Item 11	An environment with a fresh scent helps reduce stress	<0.001	<0.001	1.97E-02	<0.001	0.82	0.83	0.80
Item 12	An environment with a fresh scent is connected to a sense of renewal	<0.001	<0.001	3.24E-02	<0.001	0.68	0.70	0.65
Item 13	Fresh scents are clean scents	<0.001	<0.001	9.71E-02	<0.001	0.76	0.77	0.75
Item 14	Fresh scents are floral scents	<0.001	<0.001	<0.001	<0.001	0.35	0.37	0.32
Item 15	Fresh scents are fruity scents	<0.001	<0.001	<0.001	<0.001	0.39	0.41	0.37
Item 16	Fresh scents are outdoor scents	<0.001	<0.001	<0.001	<0.001	0.36	0.37	0.34
Item 17	Fresh scents bring a sense of comfort to my living space	<0.001	<0.001	1.94E-01	<0.001	0.86	0.88	0.85
Item 18	Fresh scents bring a sense of relaxation to my living space	<0.001	<0.001	<0.001	<0.001	0.85	0.87	0.84

Item 19	Fresh scents can influence my mood	<0.001	<0.001	1.36E-03	<0.001	0.81	0.83	0.80
Item 20	Fresh scents create a cozy atmosphere in my living space	<0.001	<0.001	9.79E-02	<0.001	0.85	0.86	0.83
Item 21	Fresh scents evoke a sense of calmness	<0.001	<0.001	9.85E-02	<0.001	0.80	0.82	0.79
Item 22	Fresh scents evoke a sense of excitement	<0.001	<0.001	<0.001	<0.001	0.54	0.56	0.51
Item 23	Fresh scents evoke a sense of happiness	<0.001	<0.001	8.16E-02	<0.001	0.80	0.81	0.78
Item 24	Fresh scents evoke a sense of well-being	<0.001	<0.001	<0.001	<0.001	0.77	0.78	0.75
Item 25	Fresh scents need to be complex	<0.001	<0.001	<0.001	<0.001	0.19	0.19	0.19
Item 26	Fresh scents need to be crisp	<0.001	<0.001	2.05E-02	<0.001	0.56	0.58	0.54
Item 27	Fresh scents need to be light	<0.001	<0.001	<0.001	<0.001	0.52	0.53	0.51
Item 28	Fresh scents need to be simple	<0.001	<0.001	<0.001	<0.001	0.57	0.59	0.55
Item 29	Fresh scents need to be strong	<0.001	<0.001	<0.001	<0.001	0.45	0.45	0.45
Item 30	Fresh scents need to mask unwanted aromas	<0.001	<0.001	<0.001	<0.001	0.77	0.77	0.78
Item 31	I associate freshness with positive emotions	<0.001	<0.001	5.75E-02	<0.001	0.80	0.82	0.78
Item 32	My choice of fresh scents is influenced by the time of year	<0.001	<0.001	<0.001	<0.001	0.67	0.70	0.64
Item 33	Scents for my home have to provide a long lasting fresh scent	<0.001	<0.001	1.42E-01	<0.001	0.86	0.87	0.85

Test for scale effectiveness

Based on the response matrix established earlier in this study, we will consider a scale statement to be "effective" for the description of freshness in air care products if it is both agreed upon and considered as "important." The scale's effectiveness is assessed by evaluating the overall correlation between the Agreement and Importance datasets, focusing specifically on the High (H) category. The primary objective is to ensure that the majority of statements exhibit a high Correct Match Rate, with minimal disagreement and neutral responses, and a low number of unmatched statements. This approach ensures a comprehensive evaluation of the alignment between the two datasets, particularly for identifying important statements with strong agreement.

In this analysis, we develop a scoring system to measure the alignment between the Agreement and Importance datasets, focusing on the High (H), Medium (M), and Low (L) categories. For the High category, we calculate the true matches (H_{match}) as the number of statements where both the Agreement and Importance datasets classify the statement as H. Unmatched statements represent instances where the Agreement dataset categorizes a statement as H, but the Importance dataset does not, and vice versa (HM, HL, MH, LH). The Correct Match Rate and Detection Rate are computed to quantify the accuracy of identifying statements in the H category.

The Correct Match Rate for the "H" class is calculated as:

$$Correct\ Match\ Rate\ = \frac{H_{\text{match}}}{H_{\text{match}} + HM + HL} \times \frac{H}{n}$$

Similarly, the Detection Rate for the "H" class is:

$$Detection\ Rate\ = \frac{H_{\text{match}}}{H_{\text{match}} + MH + LH} \times \frac{H}{n}$$

Since the calculations for both datasets are similar, we harmonize the Correct Match Rate and Detection Rate by taking the weighted average across both datasets, using the number of entries in each dataset (n_1 and n_2) as weights:

$$Correct\ Match\ Rate_{harmonized}\ = \frac{(Correct\ Match\ Rate_1 \times n1) + (Correct\ Match\ Rate_2 \times n2)}{n1\ + n2}$$

$$Detection\ Rate_{harmonized} = \frac{(Detection\ Rate_1\ \times\ n1)\ +\ (Detection\ Rate_2\ \times\ n2)}{n1\ + n2}$$

The overall score is then computed using the harmonic mean of the harmonized Correct Match Rate and Detection Rate:

$$Score\ harmonized\ =\ 2\ \times \frac{Correct\ Match\ Rate_{harmonized} \times Detection\ Rate_{harmonized}}{Correct\ Match\ Rate\ _{harmonized} + Detection\ Rate_{harmonized}}$$

A weighted factor is introduced based on the performance in the Medium category (M). The proportion p_M, representing the contribution of M to the overall matches, is calculated as:

$$p_M\ = \frac{M_{match}}{n}$$

The weighted effective score is then derived by reducing the harmonized score by a factor of $1 - p_M$:

$$Score_{weighted}\ =\ Score\ _{harmonized} \times\ (1\ -\ p_M)$$

Figure 3.2 below illustrates a 3D surface plot demonstrating how the weighted effective score is influenced by the Correct Match Rate and the Detection Rate. In this visualization, the Effective Score is modeled as a function of these two rates, with an additional weighted factor that decreases the overall score based on the proportion of Medium (M) matches.

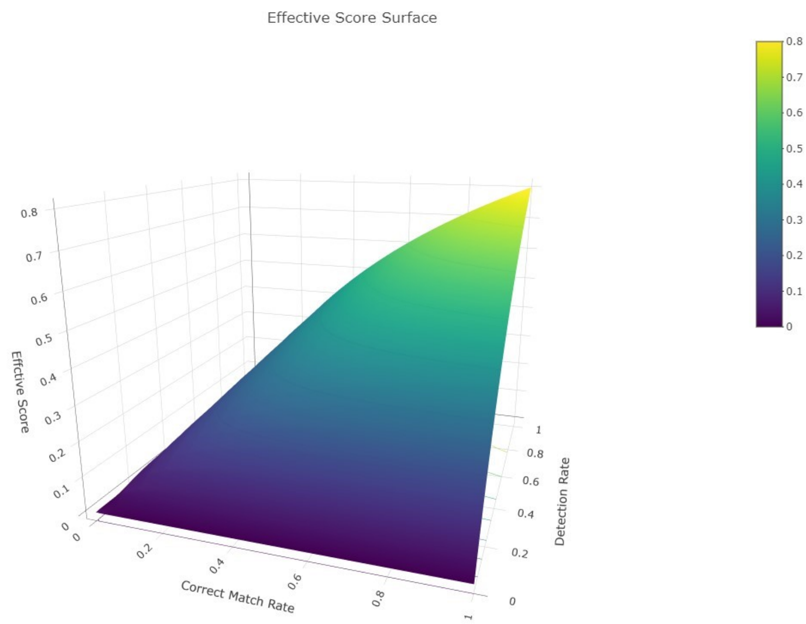

Figure 3.2: Example Visualization of effective score based on Correct Match Rate and Detection Rate

As shown in Figure 3.2, if the p_M is 0.2, which induces maximum achievable score 0.8, even when the Correct Match Rate and Detection Rate approach 1. This highlights the impact of the penalization, which prevents the score from reaching 1, reflecting the influence of Medium matches on the overall result. When either rate decreases, the Effective Score further declines, emphasizing the need to minimize unmatched statements and maintain strong detection performance. This visualization effectively demonstrates how the penalization factor moderates the final score, ensuring that the overall performance in matching and detecting the High (H), Medium (M), and Low (L) categories is taken into account.

The bar chart in Figure 3.3 illustrates the harmonized effective scores for various statements related to freshness perceptions, categorized into three performance ranges: poor (below 0.5), moderate (0.5 to 0.75), and good (above 0.75). Of the statements, numbers of Item 6 fell below 0.5, indicating poor effective performance, with examples like "Fresh scents need to be simple" and "A fresh scent creates a tingling sensation in my nose" showing considerable variability or disagreement. The details of the results are included in Table 3.4. Eleven statements fall in the moderate range, reflecting moderate performance with room for improvement, such as "An environment with a fresh scent can improve my overall quality of life." Lastly, 16 statements scored above 0.75, demonstrating strong performance, including "A fresh scent gives a feeling of cleanliness in my home" and "Scents for my home have to provide a long-lasting fresh scent." This distribution highlights where the statements perform well and where further refinement may be needed to improve consistency in statement evaluation.

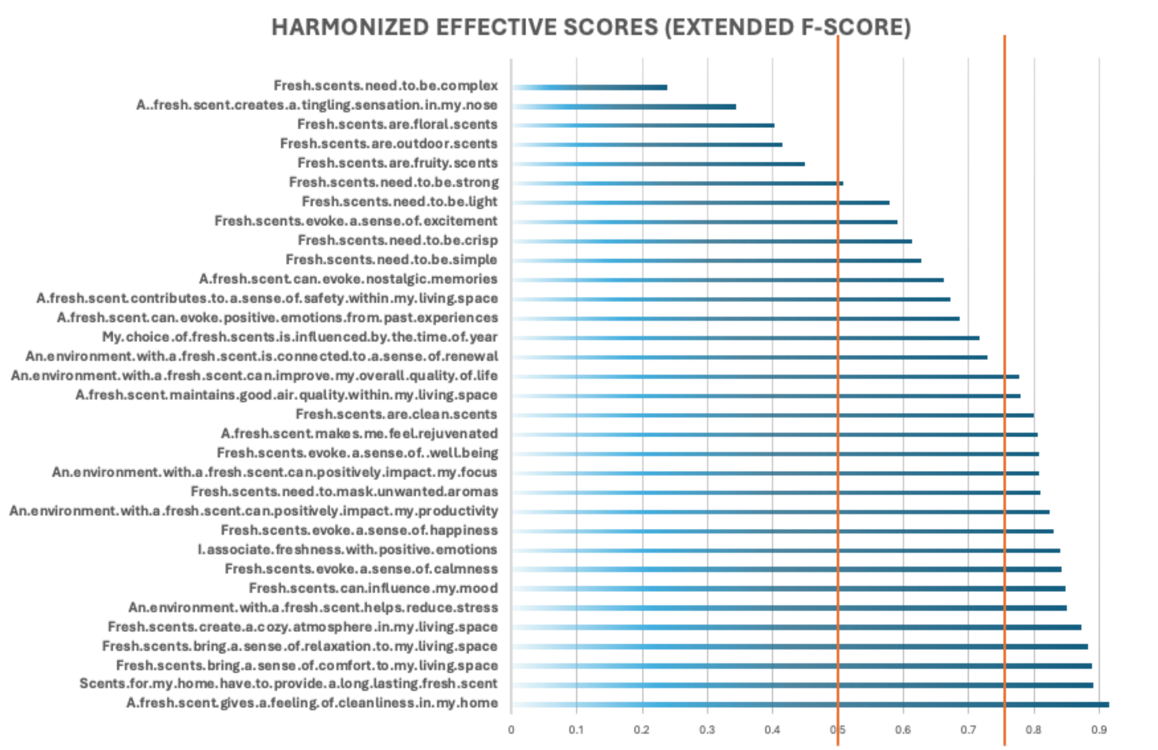

Figure 3.3: Harmonized effective scores (extended F-score) across statements for freshness perception

Test for scale consistency

Consistency of a scale refers to the measure of internal consistency, indicating how closely related a set of statements are as a group. It is a crucial aspect of scale reliability, ensuring that all statements collectively measure the intended concept. In our study, we aim to assess the internal consistency of our scale to confirm that all statements work together to measure the same underlying construct (Cho 2016; Cardello et al. 2012).

Before assessing reliability, it is important to correctly identify the underlying structure of the data. Therefore, we apply an Exploratory Factor Analysis (EFA) using the maximum likelihood (ml) method to detect potential underlying structures among the statements (Cho (2016)). The EFA helps uncover latent dimensions by analyzing the pattern of correlations within the set of statements. By performing EFA with varimax rotation on our data, we identify the number of factors that represent the data structure. This identification of the factor structure enables us to apply the appropriate reliability tests to effectively evaluate the consistency of the statements.

After the effectiveness test, we have 27 out of 33 statements remaining for verification in this step. The EFA result reveals five factors with eigenvalues greater than 1, suggesting a multi-dimensional model with 5 factors for the underlying structure. However, an examination of the eigenvalues reveals that the first eigenvalue (11.47) is substantially larger than the second eigenvalue (1.67), resulting in a ratio of approximately 6.88. This high ratio either suggests the presence of a strong general factor or supports the one-dimensionality of the scale (Hattie, 1985). Despite the initial extraction of five factors based on the Kaiser criterion (eigenvalues > 1), the dominance of the first factor indicates that a bifactor model with strong general factor or a single-factor model may be more appropriate.

After evaluating the underlying structure with EFA, we assessed the internal consistency of our scale using reliability tests of both Cronbach's Alpha and Omega. These reliability coefficients measure how well the individual statements on a scale correlate with each other. These coefficients provide an overall indication of the consistency of the scale.

Cronbach's Alpha is one of the most widely used metrics for assessing unidimensional model's internal consistency (Cho, 2016). It is based on the average inter-item correlation among the statements on a scale. The general formula for Cronbach's Alpha is given by:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum \sigma_i^2}{\sigma_T^2}\right)$$

where k is the number of statements, σi2 is the variance of each individual item, and σT2 is the total variance of the test (the sum of the covariances and variances of all the statements).

The overall Cronbach's Alpha for the scale is 0.94, indicating good internal consistency. We then examined the effect of removing each item on overall reliability by calculating the "alpha if item deleted" (α_{drop}) values. Notably, while removing Item 27 and Item 28 ("Fresh scents need to be light" and "Fresh scents need to be simple") slightly increases the alpha to 0.95, these statements may be kept as they represent important factors related to the perception of freshness. An alpha value above 0.70 is typically considered acceptable for internal consistency. Our scale achieves an alpha of 0.94, indicating good reliability.

In contrast, Omega (or Omega Total) provides a reliability estimate by accounting for the possibility that different statements may contribute to the construct to varying degrees. Omega is based on factor loadings from a factor analysis model, which evaluates the degree to which each item loads on the latent factor representing the construct. The formula for Omega Alpha is:

$$\omega = \frac{\left(\sum \lambda_i\right)^2}{\left(\sum \lambda_i\right)^2 + \sum \theta_i}$$

where λ_i represents the factor loading of each item, and θ_i is the error variance associated with each item. Omega typically produces higher estimates of reliability than Cronbach's Alpha, particularly when the statements have unequal contributions to the underlying factor.

The Omega value for the scale is 0.96, slightly higher than Cronbach's Alpha, suggesting high internal consistency even when accounting for varying item contributions. The communalities (h2) indicate that each item shares a substantial amount of variance with the underlying factor, with h2 values ranging from 0.21 to 0.72. The proportion of variance explained (p2) confirms that each item contributes meaningfully to the overall factor structure.

Item 27 and Item 28 ("Fresh scents need to be light" and "Fresh scents need to be simple") have very low p2, 0.04 and 0.07, suggesting they may not align effectively with the construct measured by the other statements. However, these statements represent key dimensions of freshness and are essential to the conceptual understanding of the scale. Based on the results from both reliability coefficients and statistical indicators, we have refined the scale by temporarily removing Item 27 and Item 28, reducing the total statements from 27 to 25, and reanalyzing the remaining statements using EFA and reliability tests. The refined scale shows improved psychometric properties, with Cronbach's Alpha increasing to 0.95 and Omega value to 0.96, while the first eigenvalue (11.41) remains substantially larger than the second (1.27), resulting in a ratio of approximately 9.00—higher than the previous ratio with 27 statements. Therefore, we propose that the freshness scale should include the 25 statements listed in Table 3.5.

We acknowledge the importance of 'light' (Item 27) and 'simple' (Item 28) as dimensions of freshness and propose that further research should explore ways to refine how these statements are framed, ensuring they better align with the overall construct. While these statements are excluded from the current version of the scale, their conceptual significance warrants revisiting them in future studies.

Table 3.5: Descriptive statistics and reliability indicators of preliminary statements

	mean	sd	raw.r	r.drop	h^2	p^2
Item 1	5.5	1.33	0.58	0.53	0.59	0.42
Item 2	5.6	1.24	0.63	0.59	0.56	0.58
Item 3	5.0	1.37	0.67	0.63	0.54	0.68
Item 5	6.1	0.99	0.66	0.63	0.52	0.75
Item 6	5.4	1.25	0.67	0.63	0.42	0.85
Item 7	5.7	1.14	0.65	0.61	0.46	0.75
Item 8	5.5	1.20	0.73	0.70	0.59	0.79
Item 9	5.8	1.13	0.72	0.69	0.59	0.77
Item 10	5.8	1.14	0.68	0.65	0.55	0.70
Item 11	5.8	1.09	0.75	0.73	0.57	0.86
Item 12	5.5	1.14	0.68	0.64	0.54	0.71
Item 13	5.6	1.08	0.53	0.48	0.31	0.74
Item 17	5.9	1.06	0.78	0.75	0.64	0.84
Item 18	5.9	1.07	0.75	0.73	0.64	0.80
Item 19	5.7	1.15	0.72	0.68	0.51	0.85
Item 20	5.8	1.13	0.69	0.65	0.49	0.82
Item 24	5.6	1.10	0.77	0.75	0.63	0.80
Item 21	5.8	1.12	0.77	0.74	0.6	0.87
Item 22	5.0	1.35	0.62	0.58	0.59	0.50
Item 23	5.7	1.09	0.79	0.77	0.66	0.83
Item 26	5.1	1.25	0.45	0.40	0.2	0.76
Item 30	5.4	1.43	0.44	0.38	0.19	0.70
Item 31	5.8	1.11	0.79	0.77	0.64	0.84
Item 32	5.3	1.47	0.48	0.41	0.29	0.51
Item 33	5.8	1.07	0.67	0.64	0.49	0.79

Test to differentiate scoring clusters

Based on the previous steps, 25 statements were selected to move forward. The mean value and standard deviation for these 25 statements are listed in Table 3.5. Consumers' ratings for each of the statements vary. The next step was to sum up all these statement scores for each participant, resulting in a total score. We applied k-means clustering via function *kmeans* in R (version 4.2.0) to the dataset of 451 participants resulting in three different clusters. The ranges for total scores within each cluster were observed: Cluster 1 had scores ranging from 64 to 128, with 115 participants; Cluster 2 had scores ranging from 126 to 152, with 150 participants; and Cluster 3 had scores ranging from 149 to 175, consisting of 186 participants.

However, due to the imbalance in participant numbers across clusters and the somewhat unclear boundaries between clusters, we employed quantile segmentation for a more robust clustering. Using this total score, we clustered the participants into three thirds and evaluated the differentiation of the scale (Yu, 2021). Cluster 1 includes 154 respondents and ranges from score 25 to 132. This was the low scoring cluster. Cluster 2 includes 148 respondents and ranges from 133 to 150. This was the moderate scoring cluster. And Cluster 3 includes 149 respondents ranging from 151 to 175. This was the high scoring cluster.

Table 3.6 shows the details of the clusters and statements with the performance of differentiability among these three clusters. Analysis was conducted using a one-way ANOVA with Tukey's post-hoc multiple comparisons. Results showed uniform differentiation, with all clusters significantly different from one another for all statements.

These findings suggest the scale's potential capability to cluster participants based on their evaluation of freshness. The consistent differentiation across clusters highlights the scale's differentiability in capturing variations in perceptions of freshness.

Table 3.6. Average statement scores for three consumer segments derived from the 25 statements selected from the freshness perception scale (agreement scores).

Statement	Cluster: Cluster 3 (n = 149) High Fresh 175>TSS>150	Cluster: Cluster 2 (n = 148) Median 150>TSS>132	Cluster: Cluster 1 (n = 154) Low Fresh 132>TSS>25	Differentiability Among Cluster
A fresh scent can evoke nostalgic memories.	6.30 a	5.59 b	4.66 c	Yes
A fresh scent can evoke positive emotions from past experiences.	6.40 a	5.69 b	4.73 c	Yes
A fresh scent contributes to a sense of safety within my living space.	6.12 a	4.99 b	4.06 c	Yes
A fresh scent gives a feeling of cleanliness in my home.	6.77 a	6.14 b	5.41 c	Yes
A fresh scent maintains good air quality within my living space.	6.46 a	5.32 b	4.60 c	Yes
A fresh scent makes me feel rejuvenated.	6.56 a	5.89 b	4.81 c	Yes
An environment with a fresh scent can improve my overall quality of life.	6.58 a	5.37 b	4.56 c	Yes
An environment with a fresh scent can positively impact my focus.	6.69 a	5.91 b	4.84 c	Yes
An environment with a fresh scent can positively impact my productivity.	6.63 a	5.84 b	4.94 c	Yes
An environment with a fresh scent helps reduce stress.	6.72 a	5.76 b	4.88 c	Yes
An environment with a fresh scent is connected to a sense of renewal.	6.38 a	5.51 b	4.66 c	Yes
Fresh scents are clean scents.	6.21 a	5.60 b	4.99 c	Yes
Fresh scents bring a sense of comfort to my living space.	6.74 a	5.98 b	4.96 c	Yes
Fresh scents bring a sense of relaxation to my living space.	6.75 a	6.05 b	4.98 c	Yes
Fresh scents can influence my mood.	6.63 a	5.88 b	4.77 c	Yes
Fresh scents create a cozy atmosphere in my living space.	6.70 a	5.89 b	4.99 c	Yes
Fresh scents evoke a sense of well-being.	6.52 a	5.64 b	4.62 c	Yes
Fresh scents evoke a sense of calmness.	6.69 a	5.88 b	4.77 c	Yes
Fresh scents evoke a sense of excitement.	6.05 a	4.86 b	4.16 c	Yes
Fresh scents evoke a sense of happiness.	6.64 a	5.83 b	4.79 c	Yes
Fresh scents need to be crisp.	5.68 a	5.14 b	4.47 c	Yes
Fresh scents need to mask unwanted aromas.	6.13 a	5.37 b	4.76 c	Yes
I associate freshness with positive emotions.	6.73 a	5.93 b	4.75 c	Yes
My choice of fresh scents is influenced by the time of year.	6.08 a	5.16 b	4.56 c	Yes
Scents for my home have to provide a long-lasting fresh scent.	6.56 a	5.84 b	5.10 c	Yes

abc: Different letters within a row indicate statistically significant differences ($p < 0.05$) based on Tukey's test

Confirmatory Factor Analysis (CFA)

We conducted Confirmatory Factor Analysis (CFA) to validate the measurement model and confirm the underlying factor structure of our scale. CFA is a statistical technique used to test whether the data fits a hypothesized measurement model, allowing us to assess the relationships between observed variables and their underlying latent constructs. To evaluate the adequacy of the model, we used multiple fit indices. The chi-square ($\chi2$) goodness of fit assesses the discrepancy between the observed and expected covariance matrices; a non-significant $\chi2$ indicates a good fit, though it is sensitive to sample size. The normed chi-square (CMIN/df) adjusts the $\chi2$ statistic by the degrees of freedom to account for sample size, with values less than 3 indicating acceptable fit. The root-mean-square error of approximation (RMSEA) measures how well the model approximates the data per degree of freedom, with values less than 0.08 suggesting a reasonable fit. The standardized root-mean square residual (SRMR) indicates the average standardized difference between observed and predicted correlations, where values less than 0.1 are acceptable. The comparative fit index (CFI), goodness-of-fit index (GFI), incremental fit index (IFI), and Tucker–Lewis index (TLI) compare the fit of our model to a null model, with values greater than 0.90 indicating a good fit.

To validate the final 25 statements, we conducted an additional test with N=154 participants recruited from the Kansas City area. These participants were selected using the same criteria as in the prior online survey with N = 451. The purpose of this step was to verify the scale's applicability in capturing freshness perception among a new but comparable cluster of participants. First, we tested the unidimensional model where all statements load onto a single factor representing the construct of interest. The fit indices for the unidimensional model are: $\chi2(df) = 956.02(275)$, $p < 0.001$; CMIN/df = 3.48; RMSEA = 0.13; SRMR = 0.09; CFI = 0.72;

GFI = 0.60; IFI = 0.72; TLI = 0.69. The chi-square statistics are significant, and several fit indices did not meet the recommended thresholds. Specifically, the RMSEA is greater than 0.08, and the CFI and TLI are below 0.90, suggesting that the unidimensional model does not adequately capture the data structure.

Considering the inadequate fit of the unidimensional model, we tested a bifactor model where each statement loads on a general factor as well as on specific factors. This approach allows us to account for both the common variance shared among all statements and the unique variance associated with specific dimensions. The fit indices for the bifactor model showed a significant improvement: $\chi 2(df) = 358.46(212)$, $p < 0.001$; CMIN/df = 1.69; RMSEA = 0.07; SRMR = 0.05; CFI = 0.94; GFI = 0.85; IFI = 0.94; TLI = 0.91. The RMSEA was below 0.08, and the CFI and TLI values exceeded 0.90, suggesting that the bifactor model provides an acceptable fit to the data.

Based on the CFA, results recommend a bifactor model over the unidimensional model. The improved fit indices suggest that accounting for both a general factor and specific factors better represents the data structure. We observe that the general factor is strong, with substantial loadings from the statements, indicating that a significant portion of the variance is explained by the general factor. However, many statements cross-load onto multiple specific factors, suggesting that the statements are not entirely distinct across factors. This cross-loading implies that while the general factor captures a large portion of the variance, the specific factors also contribute meaningfully, and the statements may be multidimensional.

Table 3.7 shows the details of the loadings of each statement on the general factor and specific factors. Based on our objectives, we evaluate the uniformity of the statements in expressing the concept of freshness. Given the nature of data-driven procedures, we identify specific factors with statistical meaning and infer potential interpretations. For factor F1, statements include Item 5, Item 6, Item 13, Item 17, Item 18, Item 19, Item 20, Item 21, Item 23, Item 30, and Item 33, which describe how scents interact with the physical environment, enhancing cleanliness and providing emotional benefits within a living space. For factor F2, statements include Item 8, Item 9, Item 10, Item 11, Item 12 and Item 26, which focus on how scents contribute to personal wellbeing and performance within various settings, emphasizing functional and psychological benefits. For factor F3, statements include Item 3, Item 22, Item 24, Item 31, and Item 32, which express contextual effects, including how freshness is perceived based on situational or temporal factors and its association with safety and positive emotions. For factor F4, statements include Item 1, Item 2, and Item 7, which express how fresh scents evoke emotional rejuvenation and connect to personal memories.

In conclusion, although the bifactor model provides a better fit, the results also indicate the existence of specific factors that reflect statistical clustering. From a scale perspective, this suggests that freshness is a multidimensional construct composed of a general factor supported by specific factors that emerge from the statistical structure of the data. These specific factors do not represent predefined theoretical dimensions but rather reflect data-driven patterns that can guide further interpretation and exploration. The results suggest that care should be taken in interpreting the factors and statements. Further research is needed to explore the theoretical implications of these findings and to assess how these factors contribute to the broader understanding of freshness perception.

Table 3.7: Factor loadings for general and specific factors of freshness perception scale statements (N = 451)

Statement (Total N = 451)		General Factor	Specific Factors			
			F1	F2	F3	F4
Item 1	A fresh scent can evoke nostalgic memories	0.50				**0.58**
Item 2	A fresh scent can evoke positive emotions from past experiences	0.57	0.08			**0.47**
Item 3	A fresh scent contributes to a sense of safety within my living space	0.60		0.21	**0.36**	
Item 5	A fresh scent gives a feeling of cleanliness in my home	0.62	**0.36**		-0.05	
Item 6	A fresh scent maintains good air quality within my living space	0.60	**0.18**	0.07	0.16	
Item 7	A fresh scent makes me feel rejuvenated	0.58		0.21		**0.26**
Item 8	An environment with a fresh scent can improve my overall quality of life	0.68	0.09	**0.31**	0.15	
Item 9	An environment with a fresh scent can positively impact my focus	0.68	0.10	**0.34**		0.10
Item 10	An environment with a fresh scent can positively impact my productivity	0.62		**0.35**		0.19
Item 11	An environment with a fresh scent helps reduce stress	0.70	0.15	**0.19**	0.12	0.07
Item 12	An environment with a fresh scent is connected to a sense of renewal	0.62		0.38		0.10
Item 13	Fresh scents are clean scents	0.48	**0.22**	0.13		-0.14
Item 17	Fresh scents bring a sense of comfort to my living space	0.74	**0.30**	0.06	0.08	
Item 18	Fresh scents bring a sense of relaxation to my living space	0.72	**0.35**			
Item 19	Fresh scents can influence my mood	0.66	**0.20**	0.10		0.16
Item 20	Fresh scents create a cozy atmosphere in my living space	0.64	**0.27**			0.13
Item 24	Fresh scents evoke a sense of well-being	0.71	0.12	0.10	0.31	0.07
Item 21	Fresh scents evoke a sense of calmness	0.72	**0.24**	0.11	0.10	
Item 22	Fresh scents evoke a sense of excitement	0.54			**0.54**	
Item 23	Fresh scents evoke a sense of happiness	0.74	**0.23**		0.22	0.08
Item 26	Fresh scents need to be crisp	0.39	0.12	**0.15**	0.05	-0.11
Item 30	Fresh scents need to mask unwanted aromas	0.37	**0.23**			
Item 31	I associate freshness with positive emotions	0.74	0.17	0.08	**0.24**	0.09
Item 32	My choice of fresh scents is influenced by the time of year	0.38	0.07	-0.14	**0.29**	0.19
Item 33	Scents for my home have to provide a long lasting fresh scent	0.62	**0.31**			

Bold numbers indicate the highest loading for each item among the Specific Factors.

Refinement of concepts

Through hypothesis testing, evaluating statement effectiveness, reliability analysis, and Confirmatory Factor Analysis (CFA), the concepts are refined to focus on the most important and consistent attributes. These refinements remove less relevant or redundant statements, ensuring that each descriptor in the concepts clearly represents the key qualities that define freshness for consumers. The results are listed in Table 3.8.

For factor F1 (Environmental Functionality), the statements emphasize the interaction of fresh scents with physical environments. This includes attributes such as maintaining air quality, masking unwanted aromas, and creating a sense of cleanliness, comfort, and relaxation in living spaces. Factor F2 (Personal Productivity) focuses on the role of fresh scents in supporting personal wellbeing and enhancing performance, including stress reduction, improved focus, and productivity in various settings. These factors capture the practical and emotional benefits of freshness in distinct but complementary contexts. Factor F3 (Contextual Associations) reflects how freshness is influenced by situational and temporal factors, capturing perceptions tied to safety, excitement, and preferences shaped by seasonal or external conditions. Factor F4 (Emotional Nostalgia) expresses the emotional connection of freshness, including its association with rejuvenation, and nostalgia. Together, these factors provide a comprehensive view of the multidimensional construct of freshness, balancing statistical robustness with meaningful consumer insights.

Table 3.8: Specific factors and the general factor of freshness perception scale statements (N = 451)

	Statement	Specific Factors				General Factor
		F1	F2	F3	F4	
Item 5	A fresh scent gives a feeling of cleanliness in my home	Environ-mental Function-ality				Fresh-ness
Item 6	A fresh scent maintains good air quality within my living space					
Item 33	Scents for my home have to provide a long-lasting fresh scent					
Item 13	Fresh scents are clean scents					
Item 17	Fresh scents bring a sense of comfort to my living space					
Item 18	Fresh scents bring a sense of relaxation to my living space					
Item 19	Fresh scents can influence my mood					
Item 20	Fresh scents create a cozy atmosphere in my living space					
Item 21	Fresh scents evoke a sense of calmness					
Item 23	Fresh scents evoke a sense of happiness					
Item 30	Fresh scents need to mask unwanted aromas					
Item 8	An environment with a fresh scent can improve my overall quality of life		Personal Producti-vity			
Item 9	An environment with a fresh scent can positively impact my focus					
Item 10	An environment with a fresh scent can positively impact my productivity					
Item 11	An environment with a fresh scent helps reduce stress					
Item 12	An environment with a fresh scent is connected to a sense of renewal					
Item 26	Fresh scents need to be crisp					
Item 31	I associate freshness with positive emotions			Contextu-al Associati-ons		
Item 32	My choice of fresh scents is influenced by the time of year					
Item 22	Fresh scents evoke a sense of excitement					
Item 24	Fresh scents evoke a sense of well-being					
Item 3	A fresh scent contributes to a sense of safety within my living space					
Item 1	A fresh scent can evoke nostalgic memories				Emotio-nal Nostalg-ia	
Item 2	A fresh scent can evoke positive emotions from past experiences					
Item 7	A fresh scent makes me feel rejuvenated					

Discussion

The concept of freshness, particularly in air-care products, is complex and often evaluated through simplified methods in consumer studies. Our study aims to improve this process by breaking down the concept of air care “freshness” into key dimensions or categories and developing a scale based on these for future product evaluations. This approach allows for a more detailed and accurate evaluation compared to the traditional method of using a single overall rating for “freshness,” which fails to take into account the individual interpretation that each respondent will give of what freshness means to them.

In many conventional studies, consumer evaluation of concepts are based on a single question, often related to their general liking, disliking, agreement, or disagreement with a concept. While this may be efficient, it overlooks potential confounding factors, it misses the possible multidimensionality of the concept. Consumers may not fully recognize the specific terms or descriptors within a concept, or they may respond to only certain parts of the concept. Furthermore, it is often unclear whether these descriptors relate to a single concept or multiple distinct ones. This is particularly problematic for abstract concepts like freshness, which involve a variety of product characteristics and consumer experiences.

In contrast, our approach involves a detailed breakdown of the freshness concept into multiple descriptors, each of which can be independently evaluated by consumers. For example, consumers might associate strong intensity with freshness due to its ability to mask unwanted odors. However, further analysis shows that a fresh scent does not necessarily need to be intense to be effective. Similarly, descriptors such as fruity and floral are not essential for a scent to be perceived as fresh. By breaking down the concept this way, we move forward from potential misinterpretations that can arise from a single, broad evaluation.

Scale effectiveness is another key aspect of our work. Effectiveness is measured by evaluating the overall alignment between the Agreement and Importance datasets, with a focus on the High (H) category. The goal is to ensure that statements exhibit a high Correct Match Rate, indicating that consumers strongly agree with the descriptors they deem important. Minimal disagreement and neutral responses in this category further confirm the accuracy of the scale. We developed a scoring system that quantifies the alignment between Agreement and Importance datasets by calculating true matches (statements categorized as H in both datasets) and unmatched statements (where one dataset categorizes a statement as H, but the other does not). This allows for a more precise measurement of how well the descriptors capture the concept of freshness.

An additional key dimension is the consistency of the scale. Consistency refers to the measure of internal consistency, which assesses how closely related a set of statements are as a group. This is a crucial aspect of scale reliability, ensuring that all statements collectively measure the intended concept. In our study, we assessed the internal consistency of the scale to confirm that all statements are working together to measure the same underlying construct. High internal consistency indicates that each statement contributes meaningfully to the overall concept, ensuring that the scale is a reliable tool for measuring consumer perceptions of freshness.

Freshness is not only a psychological concept but also a complex set of product attributes that influence consumer experience. It encompasses a wide range of factors, from emotional responses to practical product characteristics, such as air quality and scent intensity. By evaluating freshness through a set of clear, well-defined descriptors, we provide a more structured and reliable way to assess consumer perceptions. This approach can be extended to evaluate other complex product concepts, offering a more nuanced tool for product development and consumer studies.

The findings from this study demonstrate the effectiveness and consistency of the freshness concept scale. The strong agreement on important statements supports its effectiveness. The consistency of the scale is further confirmed by the results of confirmatory factor analysis (CFA), which show that the statements reliably measure the freshness concept.

In conclusion, this descriptor-based approach to evaluating freshness addresses several limitations of conventional concept evaluations. By focusing on specific, measurable descriptors, we can provide a more accurate and reliable assessment of consumer perceptions, ensuring that future product evaluations are grounded in a deeper understanding of what consumers value in freshness-related products.

Limitations of the study

One limitation of the study is the reliance on self-reported data, which can be subject to biases such as social desirability and recall bias. Additionally, the sample, while diverse, may not fully represent all demographic groups, potentially limiting the generalizability of the findings. Future research should aim to include a more diverse sample and consider alternative data collection methods to mitigate these biases. Potential biases in the study include the overrepresentation of certain demographic groups, such as females, which may influence the results. Future studies should strive for a more balanced sample to ensure broader applicability of the findings. Additionally, incorporating product usage and qualitative follow-up interviews could provide deeper insights into specific consumer preferences and behaviors.

Conclusions

The study identified key dimensions of freshness in air care products that are highly valued by consumers, including cleanliness, long-lasting scent, and positive emotional associations. The high internal consistency of the survey statements, reflected by Cronbach's alpha, confirms the reliability of these findings. The validation of focus group insights through quantitative analysis provides a robust understanding of consumer perceptions. The insights gained from this study can guide product development and marketing strategies within the air care industry. By focusing on the identified key dimensions, companies can create products that better meet consumer expectations and preferences, while also using specific marketing strategies to market and promote their products. This targeted approach can enhance customer satisfaction and brand loyalty, ultimately driving market success. Future research should aim to include a more diverse sample of consumers to ensure broader applicability of the findings. Product evaluation will also be critical to understand the applicability of the scale in the context of product usage. Longitudinal studies could provide insights into how consumer perceptions of freshness evolve over time. Additionally, exploring the impact of different marketing strategies on consumer perceptions of freshness could yield valuable information for the industry.

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Chapter 4 - Development and Validation of the Air Care Product Consumer Freshness Scale

Introduction

Freshness in air care products typically refers to the scent and overall sensory experience that makes an environment feel clean and revitalized. Consumers often associate fresh scents with cleanliness, comfort, and wellbeing. This concept is crucial in the air care industry as it directly influences consumer preference and satisfaction. Understanding how consumers perceive freshness is vital for product development and marketing strategies (Ares et al., 2015). It allows companies to align their products with consumer expectations, thereby increasing satisfaction and brand loyalty. By grasping these perceptions, businesses can tailor their offerings to better meet consumer needs and stand out in a competitive market (Cheng et al., 2020; Wang et al., 2019).

Freshness is a critical attribute, not only for foods, but also in the air care and fragrance industry, where it influences consumer behavior through sensory and emotional responses (Farruggia et al., 2016; Tsiros and Heilman, 2005). Unlike food products, where freshness is tied to attributes such as taste and texture, and related to spoilage and product quality, freshness in non-food categories such as air care and perfumes is strongly associated with olfactory properties, such as scent clarity, intensity, and longevity (Thiboud, 1991). The evolving consumer demand for these products highlights the importance of the emotional dimension in addition to hedonic and performance aspects. This emotional connection, harmonized with consumer expectations, can become a differentiating factor in scent development (Rodriguez et al., 2024).

The emotional responses evoked by scents play a crucial role in consumer perceptions of freshness. Olfactory cues, particularly in personal and home care products, have a strong influence on emotional processing, often through associative learning (Rodriguez et al., 2024). While both conscious and unconscious responses contribute to the overall experience of a product's freshness, verbal reports of subjective feelings are frequently used to measure consumer emotions elicited by scents. The ability to quantify these emotional responses, whether through verbalization or other methodologies, provides valuable insights into how freshness is perceived in different cultural contexts and real-life situations (Peneau et al., 2009).

Furthermore, freshness in perfumes is characterized by scent families such as citrus, green, and aquatic, often associated with top notes due to their high volatility (Thiboud, 1991). These scents create an immediate burst of freshness but evaporate quickly, requiring product innovations that enhance freshness perception over time. Recent research into multisensory experiences has shown that auditory elements, like brand-aligned soundtracks, can also modulate how freshness is perceived in fragrances, creating more immersive and emotionally resonant product experiences (Rodriguez et al., 2024). This highlights the potential for non-scent cues, such as sound and packaging, to further elevate the freshness and emotional appeal of air care and perfume products.

The development of a freshness scale could be critical to evaluate various dimensions of freshness perception for products with different aroma profiles. Previous studies have highlighted the importance of scent in influencing consumer preferences and product satisfaction. By developing a reliable scale, this study aims to enhance the understanding of how different scents contribute to the overall perception of freshness (Koster and Mojet, 2015).

This study seeks to determine performance of the scale in a product usage setting, and how effectively the freshness scale can differentiate between products based on various scent-related attributes. Specific questions include whether certain scent characters are more closely associated with perceptions of freshness than others. Additionally, the study investigates how environmental and emotional contexts influence the perception of freshness.

The main objectives are to assess if the freshness concept contributes to consumers' overall liking and to test the effectiveness of the freshness scale in differentiating products. By understanding the emotional and sensory aspects of freshness, this study aims to gain insights into how consumers perceive freshness in air care products. The focus will be on both the conscious emotional responses elicited by these products and the multisensory elements that can enhance the perception of freshness. The study will also explore how product attributes such as scent longevity and environmental context influence consumer expectations and emotional responses.

Methods

Study design

The study included a total of 154 participants from the Kansas City Area, each of whom evaluated two products. One participant did not complete the survey, leaving 153 responses recorded. The demographics are listed in Table 4.1. The participants engaged in a Home Use Test, where they evaluated each product over a 5-day period with a 1-week rest period between products. Four different aromas of products were assessed (Figure 4.1): Fruity Gourmand (N=77), Floral (N=78), Tropical Fruity (N=75), and Linen Clean (N=76), using an incomplete randomized block design where each participant randomly received and evaluated 2 out of 4 products. This design was generated via Compusense. Before evaluating products, every participant received the freshness concept scale questionnaire which developed from prior online survey study to understand their perception of freshness. After evaluating each product, participants received a freshness product scale questionnaire to generate their perceptions and attitudes to freshness of products.

Figure 4.1: Four samples explored in Home-Use-Test

Table 4.1: Demographic of Home-Use-Test participants (N = 153)

Gender	Percentage
Male	23%
Female	77%
Age	%
18-34 Years	14%
35-50 Years	63%
51-65 Years	22%
Purchasing Behavior	%
I do all or most of the shopping for my household	88%
I share the responsibility equally with someone else	12%
Household Product Use	%
Air care/fragrances	100% (Q)
Cleaning/disinfectant	100%
LED lightbulbs	100%
Fan/humidifier	93%
Carpet cleaners	88%
Cat litter	36%
Security cameras	73%
Air Care Product Use	%
Aerosol air fresheners	93%
Scented candles	94%
Plug-in scented oils	100% (Q)
Aromatherapy diffusers	72%
Battery powered automatic sprays	36%
Slow-release gels	47%
Reed diffusers	52%
Brands of Product	%
Febreze	93%
Air Wick	67%
Glade	83%
Bath & Body Works	87%
Yankee Candle	70%
Renuzit	26%
Method	39%
Store Brand	11%
Other Brand	11%

(Q) Qualification Mandatory, participants had to be users of air care and plug-in scented

Product-related freshness questionnaire construction

The questionnaire for the product-related scale was developed based on features identified in previous focus group and online survey studies. For each feature in the freshness concept, we modified the conceptual description from “freshness” to “the product”. For example, the statement “Fresh scents need to be crisp” would be modified to “The scent of this product is crisp”. This would ensure that the scale is now directly applicable to product usage. There was a total of two phases in the constructed questionnaire.

Phase I: General questions related to products

Hedonic and Likert-type scale-based questions for consumers’ perceptions have been widely used. These questions effectively uncover consumers’ hedonic responses and their attitudes towards products. To uncover the relation between product-related freshness perceptions and consumers hedonic measures, we first need to collect consumers’ perception from hedonic measures. Therefore, we added five questions including overall liking, freshness “intensity” perception, aroma liking, meet expectation, and purchase intent of the product.

Phase II: Product related freshness scale

A total of 25 statements were generated based on previous work on the product related freshness scale, as shown in Table 4.2. The key features of these 25 statements were verified in prior studies to be effective in the measurement of freshness perception. A 7-point Likert-type (going from “strongly disagree” = “1” to “strongly agree” = “7”) scale was used for evaluating each statement.

Table 4.2 Product related freshness scale statements

	Statement
Environmental Functionality	The scent of this product adds to the cleanliness of my home.
	The scent of this product contributes to good air quality.
	The scent of this product is long-lasting.
	The scent of this product has a clean character.
	The scent of this product brings a sense of comfort to my living space.
	The scent of this product promotes relaxation.
	The scent of this product can uplift my mood.
	The scent of this product creates a cozy atmosphere in my living space.
	The scent of this product brings calmness.
	The scent of this product brings happiness.
	The scent of this product masks unwanted aromas.
Personal Productivity	The scent of this product enhances quality of life.
	The scent of this product enhances focus.
	The scent of this product boosts productivity.
	The scent of this product reduces stress.
	The scent of this product brings a sense of renewal.
	The scent of this product is crisp.
Contextual Associations	The scent of this product evokes positive emotions.
	The scent of this product is uniquely seasonal.
	The scent of this product adds excitement to my living space.
	The scent of this product contributes to overall well-being.
	The scent of this product contributes to a sense of safety.
Emotional Nostalgia	The scent of this product can bring back positive emotions from past experiences.
	The scent of this product can evoke nostalgic memories.
	The scent of this product rejuvenates my senses.

Data analysis

We used ANOVA with Tukey post-hoc comparison to assess the relationships of general questions and scale statements to the products' aroma types. Then, we used the scale's results to group consumers and do further analysis.

We calculated a total sum score for groups of Low, Moderate, and High levels. The total sum score 25 – 100 was considered as Low; 101 – 125 was considered as Moderate; and 126 – 175 was considered as High. To ensure that the product-related freshness scale is actually related to the perception of freshness, we 1) evaluated the differentiability of the groups (different levels of freshness) to the statements in the scale; 2) evaluated the relationships between the groups and consumers' perception of overall liking; 3) evaluated the relationships between the groups and consumers' perception of freshness "intensity"; 4) evaluated the relationships between consumers' perception of freshness "intensity" and overall liking; and 5) evaluated the reliability of the statements. In addition, we also evaluated the differences in "freshness" perception among products according to the product related scale's statements.

To investigate the potential relationship between the freshness concept and overall liking, A Propensity Score Matching (PSM) was employed to control confounding variables. Age and gender were used as covariates in the propensity score model to adjust for any demographic differences that might affect both the perception of freshness and overall liking. A generalized boosted model was used to estimate propensity scores, with the Average Treatment Effect (ATE) as the "estimand", and "es.max" was used as the stopping criterion to maximize covariate balance.

After calculating the propensity scores, weights were generated and applied to a weighted linear model, where overall liking was the dependent variable, and the freshness concept ratings were used as the predictor. This approach allowed for the estimation of the potential effect of freshness perception on overall liking by adjusting for potential confounders. The use of PSM ensured that the relationship between freshness concept and overall liking was not biased by imbalances in age or gender across the treatment groups.

Once the potential relationship between freshness and overall liking was detected, a detailed analysis was performed to compare how individual treatments (Low, Moderate, High) influenced ratings of the 25 concept statements related to product freshness. A new set of Propensity Score Matching (PSM) was conducted to adjust for differences in age and gender across the three treatment groups, ensuring balanced comparisons. The PSM weights were applied to weighted linear models, where the treatment group was used as the independent variable and each of the 25 concept statements was analyzed as the dependent variable.

Post-hoc pairwise comparisons were conducted using Tukey's Honest Significant Difference (HSD) test to identify statistically significant differences between the treatment groups (Low, Moderate, High) for each concept statement. The results of these comparisons were displayed using compact letters (a, b, c), where different letters indicated significant differences between the groups. This analysis provided insight into how treatment groups affected consumer perceptions of specific concept statements.

In addition to treatment comparisons, the study also aimed to assess differences in concept statement ratings among the products evaluated. For this analysis, another round of Propensity Score Matching (PSM) was performed, this time adjusting for age and gender while excluding sample identity from the covariates. The goal was to compare concept statement ratings across samples while controlling demographic imbalances.

A mixed-effects model was used to account for repeated measurements, with sample identity as the fixed effect and consumer identity as a random effect to account for individual level variability in responses. This model allowed for proper control over within-consumer correlation when comparing concept statement ratings across different product samples. Post-hoc pairwise comparisons between samples were performed using Fisher's LSD, and adjustments for multiple comparisons were applied to maintain statistical validity. This analysis helped to determine if and how concept statement ratings differed across products after adjusting for demographic covariates.

All statistical analyses were conducted using ***R*** version 4.2.0. Propensity Score Matching was performed using the ***twang*** package, and both linear models and mixed-effects models were fitted using the ***lme4*** package. Post-hoc pairwise comparisons were conducted using the ***emmeans*** package, and compact letter display was generated with the ***multcomp*** package. These tools allowed for robust comparisons across treatments and samples, ensuring that results were appropriately adjusted for confounding demographic factors.

Results

Product assessment metrics

Table 4.3 compares overall liking, aroma liking, freshness intensity, purchase intent, and expectation of the four air care products evaluated: Fruity Gourmand, Floral, Tropical Fruity, and Linen Clean. According to the results, Tropical Fruity and Linen Clean received the highest overall liking score (6.9) but were not significantly different from the Fruity Gourmand product (6.5) and Floral (6.3). Tropical Fruity led in aroma liking (7.2) which is significantly higher than the score of Floral (6.3) but were not significantly higher than Linen Clean (6.9) and Fruity Gourmand (6.6). For freshness "intensity" perception, the Linen Clean and Floral scores scored 5.2 and 5.0 respectively, and were significantly higher than the Tropical Fruity product (4.1), and Fruity Gourmand (4.4), which scored as the lowest "freshness" perception. The purchase intent for Linen Clean and Tropical Fruity were significantly higher than the Fruity Gourmand and Floral. No significant differences among these samples were detected in consumers' expectations.

Interestingly, results show that overall "freshness" perception is not necessarily a characteristic associated with product liking. Results show that even though Tropical Fruity received the highest overall liking and aroma liking scores, it also received the lowest score for overall "freshness" perception. This tells us that even though, "freshness" perception is considered a positive feature in scents, it is not the only factor driving liking. Other factors such as scent character, scent intensity, and environment context can affect how much a scent is liked. Further exploration showed that correlation between overall "freshness" perception and overall liking was (0.28), while the correlation between overall "freshness" and aroma liking was (0.24). This confirms a poor correlation between these metrics.

Table 4.3. General questions test results for four air fresheners scents

	Fruity Gourmand	Floral	Tropical Fruity	Linen Clean
Overall liking	6.5	6.3	6.9	6.9
Aroma Liking	6.6ab	6.3b	7.2a	6.9ab
Freshness Strength	4.4b	5.0a	4.1b	5.2a
Purchase Intent	2.9b	3.0b	3.2ab	3.4a
Expectation	3.1	3.1	3.1	3.3

abc: Different letters within a row indicate statistically significant differences ($p < 0.05$) based on Fisher's test.

Table 4.4 shows the mean results for each of the four air care products evaluated and the 25 product freshness scale statements used. Some trends are evident. A total of 11 out of 25 statements showed significant differences among the four products evaluated. With the exception of the statement "The scent of this product is uniquely seasonal", Linen Clean received significantly higher ratings compared to the other products evaluated. The statement "The scent of this product is uniquely seasonal," is a reversed attribute. This means that according to the freshness concept scale, "fresh" products should have a low seasonality score, meaning that they are not bound by seasonal needs. The Linen Clean product received the lowest value for this statement and was significantly lower compared to the other products evaluated. This is in line with the concept of freshness proposed. Other statements where the Linen Clean product was significantly higher, were adding cleanliness to the home, boosting productivity, adding a sense of renewal, contributing to a sense of safety and good air quality, enhancing focus, and having a clean, crisp, long lasting aroma character scent that masks unwanted aroma. All these are features we propose as characteristics of “fresh” aromas in air-care products.

Table 4.4: Product related freshness scale test results for the four air care products

	Statements	Fruity Gourmand	Floral	Tropical Fruity	Linen Clean
Environmental Functionality	The scent of this product adds to the cleanliness of my home.	4.74b	4.95b	4.91b	5.53a
	The scent of this product contributes to good air quality.	4.45b	4.61ab	4.61ab	5.05a
	The scent of this product is long-lasting.	5.00b	5.51a	4.55b	5.86a
	The scent of this product has a clean character.	4.67b	5.11b	4.68b	5.76a
	The scent of this product brings a sense of comfort to my living space.	4.48	4.63	4.87	4.97
	The scent of this product promotes relaxation.	4.34	4.46	4.51	4.47
	The scent of this product can uplift my mood.	4.60	4.57	4.98	4.81
	The scent of this product creates a cozy atmosphere in my living space.	4.41	4.53	4.54	4.70
	The scent of this product brings calmness.	4.47	4.54	4.46	4.71
	The scent of this product brings happiness.	4.63	4.75	5.00	4.88
	The scent of this product masks unwanted aromas.	4.69b	5.12ab	4.75b	5.38a
Personal Productivity	The scent of this product enhances quality of life.	4.15	4.27	4.34	4.53
	The scent of this product enhances focus.	3.88b	3.96b	3.72b	4.40a
	The scent of this product boosts productivity.	4.08ab	4.00b	4.12ab	4.50a
	The scent of this product reduces stress.	4.23	4.27	4.53	4.49
	The scent of this product brings a sense of renewal.	4.21b	4.45ab	4.42ab	4.85a
	The scent of this product is crisp.	4.61b	4.82ab	4.71ab	5.16a
Contextual Associations	The scent of this product evokes positive emotions.	4.62	4.64	5.07	4.94
	The scent of this product is uniquely seasonal.	3.79a	3.98a	4.02a	2.70b
	The scent of this product adds excitement to my living space.	4.08	4.20	4.50	4.23
	The scent of this product contributes to overall well-being.	4.42	4.47	4.72	4.72
	The scent of this product contributes to a sense of safety.	3.57b	3.86ab	3.64b	4.05a
Emotional Nostalgia	The scent of this product can bring back positive emotions from past experiences.	4.00	4.14	4.05	4.03
	The scent of this product can evoke nostalgic memories.	3.93	4.12	3.90	3.82
	The scent of this product rejuvenates my senses.	4.43	4.44	4.68	4.76

abc: Different letters within a row indicate statistically significant differences ($p < 0.05$) based on Fisher's test

The Floral product was positioned closer to the Linen Clean product compared to the other scent types for the 11 significant statements, as shown in Figure 4.2. The PCA plot (Figure 4.2a) illustrates the distribution of different scent products across two principal components, with F1 and F2 accounting for 87.91% and 8.86% of the variance, respectively. Floral and Linen Clean are positioned in the right half of the plot, indicating that they share similarities in attributes such as cleanliness, renewal, and productivity-enhancing qualities. However, their exact positioning is not identical, indicating some distinctions between them. Ten statements are located in the right half of the plot along with the "Freshness Intensity" statement, highlighting their similarity in freshness attributes. The only statement positioned distinctly is "The scent of this product is uniquely seasonal," which is situated in the opposite direction. This statement is different from the others, as it was invested in serving as an indicator to check the quality of the overall responses. We expect the results for this statement to be reversed if the responses are of good quality.

The Agglomerative Hierarchical Clustering (AHC) shown in Figure 4.2b further supports the similarity between Floral and Linen Clean by clustering them together, whereas Tropical Fruity and Fruity Gourmand are positioned separately. This indicates that, while Floral aromas exhibit “fresh” characteristics similar to Linen Clean, there are still nuances that differentiate them. On the other hand, Fruity and Gourmand scents have less association with freshness attributes, as shown by their separation in both PCA and AHC analysis.

Overall, these results show that Floral scents are more similar to Linen Clean in terms of perceived freshness, while still having some unique features. The cluster analysis also confirms this observation. This means that Floral scents can be considered "fresh" products, more than fruity or gourmand scents.

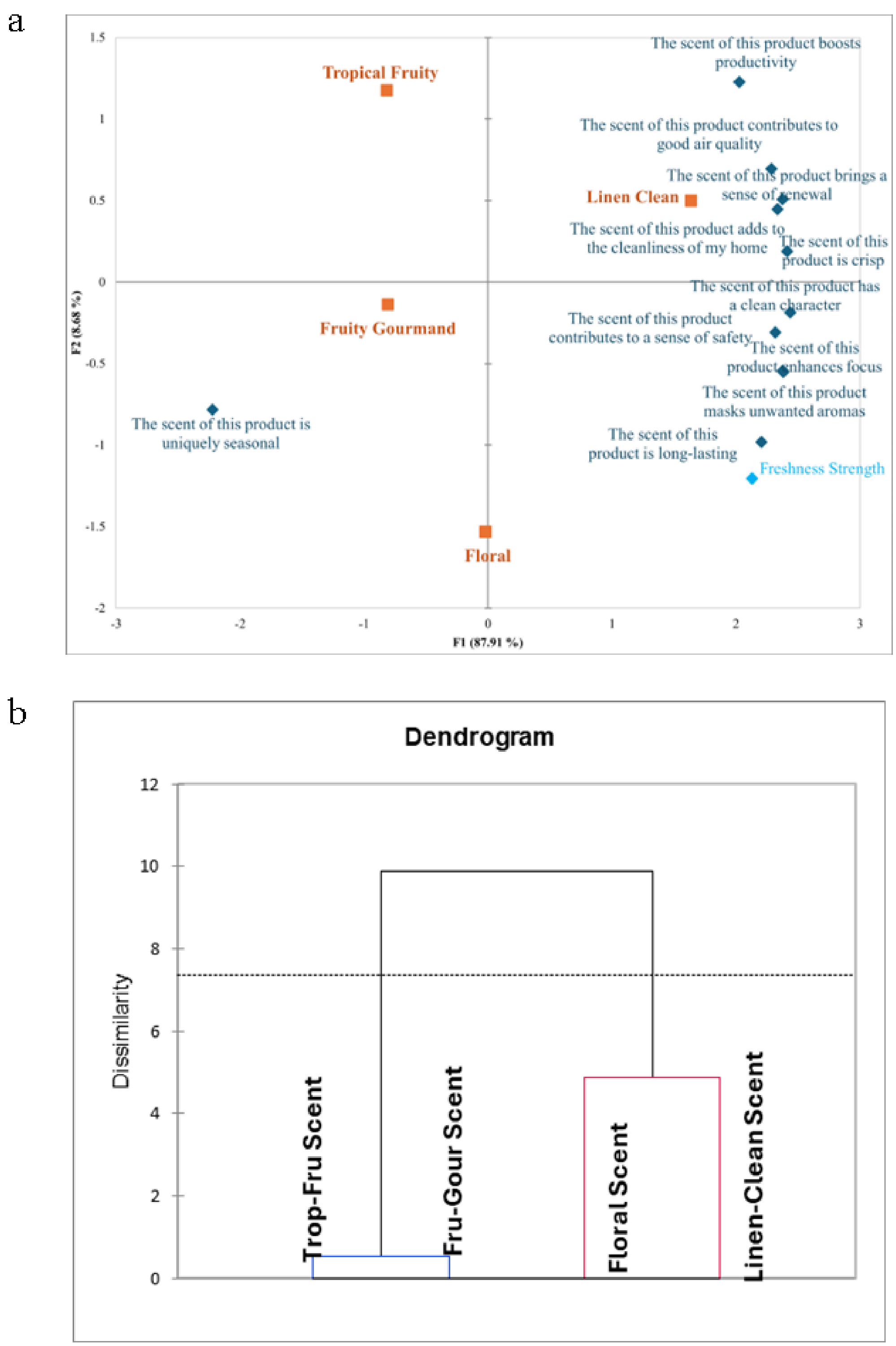

Figure 4.2 : Principal Component Analysis and Cluster Analysis for the 11 significantly different statements. (a) Biplot for Principal Component Analysis; b) Agglomerative Hierarchical Clustering

Product scale evaluation

Propensity scores results

Initial results suggested that there is not a direct relationship between freshness perception and hedonic scores even though significant differences were detected. However, other covariates exist with the stimulus such as consumers' age, gender, their own opinions of the concept of freshness, and the different scents evaluated, which could have an effect on the results. Some of these covariates may be unbalanced due to natural variability in demographic characteristics or differences in individual aroma preferences. For example, age and gender might influence the ability to perceive the intensity of aroma characters, leading to an uneven distribution of responses across the different groups. Additionally, personal opinions on freshness and familiarity with specific scents can vary among participants, contributing to covariate imbalance. Therefore, additional analysis aims to balance these covariates and explore if any effects exist among freshness perception from the product related scale, freshness "intensity," and hedonic measures.

Figure 4.3 shows the covariates before and after balance. Standardized Mean Differences (SMD) and raw mean differences between groups, with smaller values indicating a better covariate balance. The closer the points are to zero on the x-axis, the more balanced the covariates are between the treatment groups. Four types of covariates balance are shown, represented by the red and blue dots. The red dots indicate the covariate imbalance before adjustment (unadjusted sample), and the blue dots show the covariate balance after adjustment (adjusted sample). Ideally, all covariates should be as close to zero as possible after adjustment, which means that the treatment groups are comparable to those variables. The dashed vertical line at 0.1 marks a common threshold for acceptable balance ($SMD < 0.1$), indicating that any points to the left of this line are considered well-balanced. In this plot, the blue dots are generally closer to zero than the red dots, suggesting that the adjustment process has successfully improved covariate balance between the groups, which is a key goal in PSM to reduce confounding factors and better isolate the expected treatment effects. Table 4.2 and 4.3 present the analyzed results before applying propensity score adjustments, providing insight into how the covariates were distributed before any correction was made. Using adjusted scores in further analysis not only supports that observed effects are attributed to the treatment we expected rather than other covariates, but also potentially uncovers how these covariates affect the treatment outcomes.

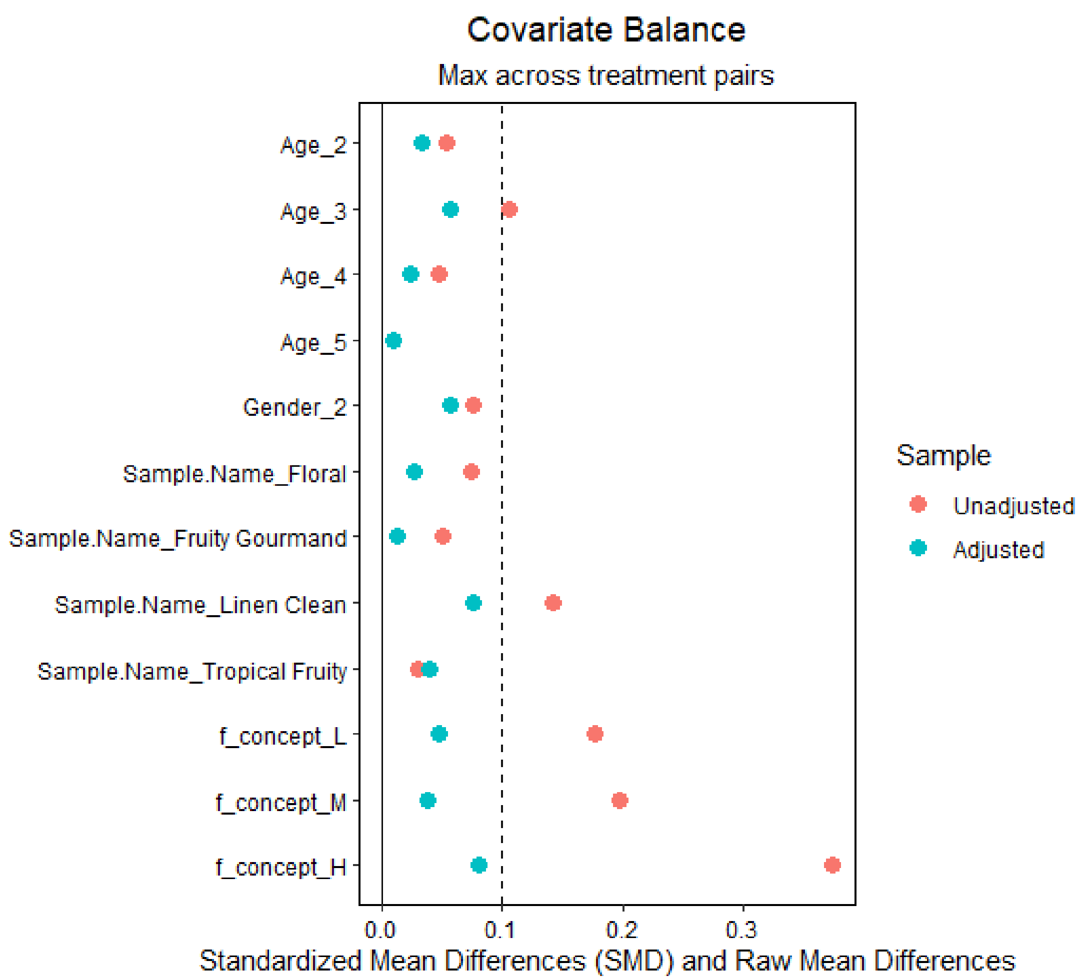

Figure 4.3: The mean difference before and after balancing for age, gender, product aroma types, and freshness concept perception.

Groups of product related freshness

After balancing, we used propensity scores as the weight in the general linear model to evaluate whether significant differences existed. First, we checked the differentiability of these statements among three groups of Low, Moderate, and High ratings as described below. Results shown in Table 4.5 suggest good differentiability for these statements, suggesting that people with different freshness rating scores rated statements differently. All statements showed highest ratings for the High Fresh group, median ratings for the Moderate group and Lowest ratings for the Low Fresh group, except the statement "The scent of this product is uniquely seasonal". This statement was reviewed for internal standard validation. The reversed results are evidence of good data quality. A total of 22 out of the 25 statements evaluated were significantly different from each other among the three groups. The following statements: "The scent of this product masks unwanted aromas", "The scent of this product is uniquely seasonal" and "The scent of this product is long lasting" show a trend from high freshness to low freshness even though there was not a significant difference detected between the Moderate, High, and Low groups.

The total sum scores separated by the three groups of freshness perception shows a trend in perception. This trend is consistent with the hypothesis that freshness level for product context has a tendency to be measured. Therefore, we could use the groups to determine the product freshness perception level.

Table 4.5. Statements and their average scores for the three consumer segments from the product freshness scale

Statement	Group: Group 3 (n = 112) High Fresh 175>TSS>126	Group 2 (n = 104) Moderate 125>TSS>101	Group 1 (n = 88) Low Fresh 100>TSS>25	Significance Among all Groups
The scent of this product can evoke nostalgic memories.	5.03 a	3.93 b	2.63 c	Yes
The scent of this product can bring back positive emotions from past experiences.	5.27 a	4.01 b	2.63 c	Yes
The scent of this product contributes to a sense of safety.	4.87 a	3.70 b	2.54 c	Yes
The scent of this product adds to the cleanliness of my home.	6.25 a	5.19 b	3.34 c	Yes
The scent of this product contributes to good air quality.	5.94 a	4.87 b	2.91 c	Yes
The scent of this product rejuvenates my senses.	5.97 a	4.66 b	2.76 c	Yes
The scent of this product enhances quality of life.	5.63 a	4.34 b	2.70 c	Yes
The scent of this product enhances focus.	5.27 a	3.90 b	2.54 c	Yes
The scent of this product boosts productivity.	5.59 a	4.07 b	2.56 c	Yes
The scent of this product reduces stress.	5.68 a	4.43 b	2.72 c	Yes
The scent of this product brings a sense of renewal.	5.83 a	4.59 b	2.71 c	Yes
The scent of this product has a clean character.	6.15 a	5.17 b	3.58 c	Yes
The scent of this product brings a sense of comfort to my living space.	6.25 a	4.77 b	2.84 c	Yes
The scent of this product promotes relaxation.	5.80 a	4.55 b	2.67 c	Yes
The scent of this product can uplift my mood.	6.09 a	4.77 b	3.04 c	Yes
The scent of this product creates a cozy atmosphere in my living space.	5.98 a	4.64 b	2.67 c	Yes
The scent of this product contributes to overall well-being.	5.94 a	4.57 b	2.92 c	Yes
The scent of this product brings calmness.	5.92 a	4.64 b	2.75 c	Yes
The scent of this product adds excitement to my living space.	5.56 a	4.23 b	2.66 c	Yes
The scent of this product brings happiness.	6.11 a	4.94 b	3.07 c	Yes
The scent of this product is crisp.	5.84 a	4.84 b	3.55 c	Yes
The scent of this product masks unwanted aromas.	5.77 a	4.70 b	4.37 b	
The scent of this product evokes positive emotions.	6.07 a	4.94 b	3.11 c	Yes
The scent of this product is uniquely seasonal.	4.17 a	3.63 ab	2.96 b	
The scent of this product is long lasting.	6.05 a	4.82 b	4.74 b	

abc: Different letters within a row indicate statistically significant differences ($p < 0.05$) based on Fisher's test.

Relationship between product-related scale, freshness perception, and hedonic measures

Figure 4.4 illustrates the effectiveness of the product-related scale. By leveraging propensity scores which balance covariates such as participants' age, gender, product aroma types, and basic perceptions of freshness, we observed significant effects of freshness level (High, Moderate, Low) on freshness "intensity." This shows that the features measured by the product related freshness scale, and the groups defined by the scale, effectively represent consumers' perceptions of freshness.

Figure 4.4 also shows consumers' perceptions of freshness "intensity" significantly affect overall liking, indicating a strong association between freshness perception and hedonic measures. Additionally, the groups from the freshness scale significantly influence overall liking, suggesting that higher ratings of freshness perception are generally associated with higher liking scores, while lower ratings of freshness perception are related to lower liking scores. These findings highlight the effectiveness of our freshness scale in capturing consumers' perceptions and their hedonic preferences.

The difference between the initial correlation and the weighted analysis may be due to the presence of confounding variables. The raw correlation did not account for these confounders, which could have obscured the relationship between freshness intensity and overall liking. By using propensity scores to control these factors, we isolated the effect of freshness intensity and found a significant impact on overall liking. Correlation analysis provides a basic measure of a linear relationship, but it does not account for other influencing factors. In contrast, regression analysis, such as the GLM used here, can model more complex relationships and adjust for confounding variables. This is why regression revealed a significant effect of freshness intensity and overall liking, even though the initial correlation appeared weak.

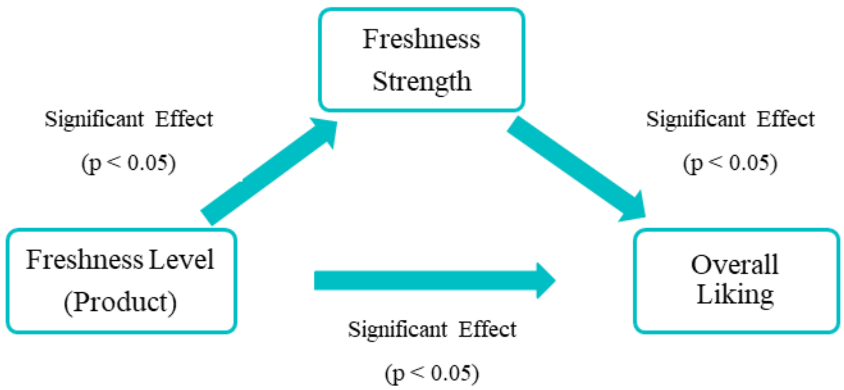

Figure 4.4. The relationship effects among the product freshness level (groups), freshness strength and overall liking

Exploration of the impact of different freshness perception tendencies on product evaluation

Figure 4.5 is similar in structure to Figure 4.3; it depicts the covariates before and after balance. However, the difference between the two analyses is that Figure 4.3 includes samples' aroma types in the propensity score calculation, while Figure 4.5 does not. This difference allows us to assess the impact of including or excluding aroma types on covariate balance. We used similar standards to evaluate the balancing results. Figure 4.5 shows the Standardized Mean Differences (SMD) and raw mean differences between groups, with smaller values indicating an improved balance. The closer the points are to zero on the x-axis, the more balanced the covariates are across treatment groups. Three types of covariate balance are shown, represented by the red (unadjusted sample), and blue dots (adjusted sample). Ideally, after adjustment, covariates should be as close to zero as possible, implying comparability between treatment groups. The dashed vertical line at 0.1 marks a common threshold for acceptable balance (SMD < 0.1). Any points positioned to the left of this line indicate well-balanced covariates. In this plot, the blue dots are generally closer to zero than the red dots, suggesting that the adjustment process has successfully improved covariate balance between the groups, which is a key goal in PSM to reduce confounding factors and better isolate the expected treatment effects.

The balanced covariates include age, gender, and the three levels of freshness concept. We will further explore consumers' overall liking and freshness perception across different aroma types within the freshness groups.

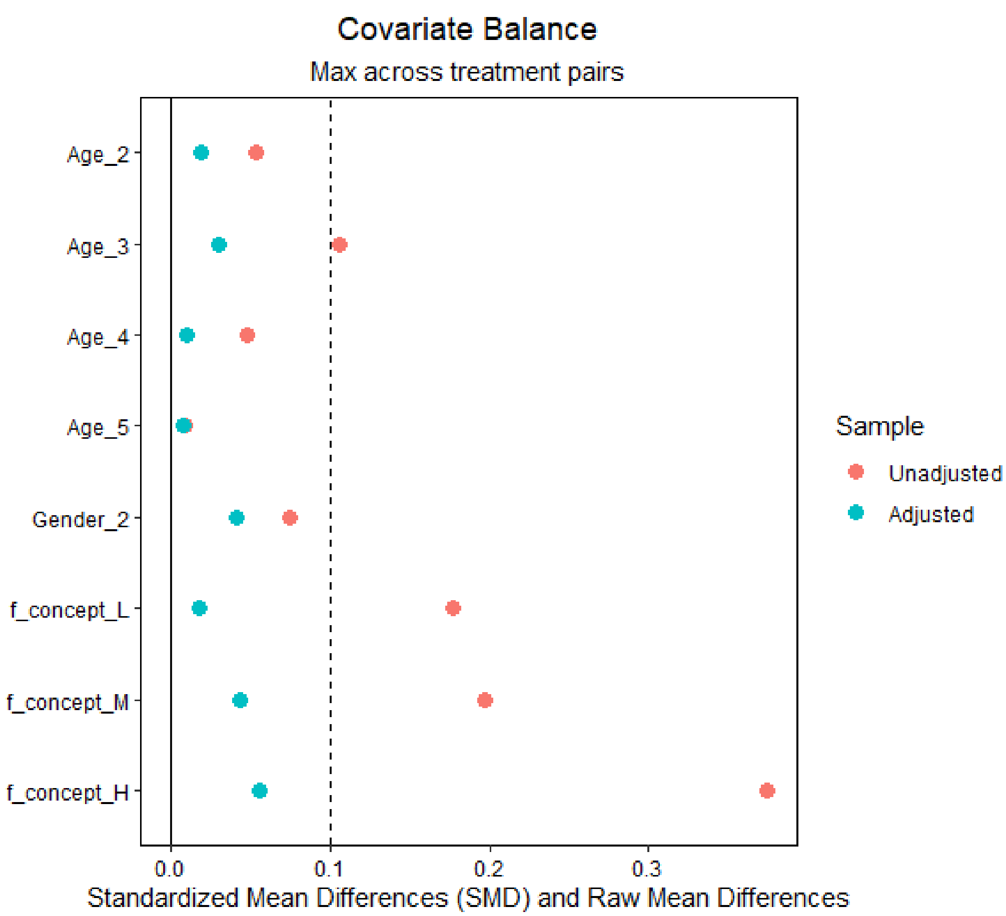

Figure 4.5: The mean difference before and after balancing for age, gender and freshness concept perception.

Product comparisons among freshness groups

In brief, the freshness level identified by the scale has a general positive association with liking and perceived freshness intensity, though this relationship is not strictly linear. Table 4.6 shows least square means of consumer ratings for overall liking and freshness "intensity" across the three freshness groups. For overall liking, we observed that significant differences existed between the High Freshness group and the Low Freshness group, and overall liking ratings increased consistently as the freshness group moved from Low to High. This suggests that there is an association between overall liking and scale ratings. This does not necessarily mean a cause and effect where high freshness means higher liking but suggests that consumers that tend to provide higher scores for the scale statements, also score higher liking. Floral and Linen Clean products showed significant differences between all three groups, while Fruity Gourmand and Tropical Fruity displayed significant differences between Low and High groups, and with less distinct differences between Moderate and High.

A similar trend was found for freshness "intensity" as well. The High freshness group corresponded to greater perceived freshness "intensity" across all samples. Significant differences were found between High Freshness group and Low Freshness group, and the Moderate Freshness group was located in between. In general, these findings suggest that consumers that score higher ratings in the scale, also tend to score higher for the freshness "intensity" score. Different products, however, show some different trends that we will proceed to explore in the next section.

Table 4.6. Least square means for rating on product ratings divided by each freshness group

Questions	Products	Groups		
		Group Low	Group Moderate	Group High
Overall Liking	Floral	4.27 c	6.95 b	8.23 a
	Fruity Gourmand	4.52 b	6.91 a	7.62 a
	Linen Clean	3.89 c	6.77 b	8.03 a
	Tropical Fruity	5.56 b	7.19 a	7.64 a
Freshness Intensity	Floral	4.38 b	4.83 ab	5.45 a
	Fruity Gourmand	3.60 b	4.2 b	5.22 a
	Linen Clean	4.66 b	5.07 ab	5.59 a
	Tropical Fruity	3.25 b	4.06 b	4.51 a

abc: Different letters within a row indicate statistically significant differences ($p < 0.05$) according to Fisher's test

Product comparison within freshness groups

For overall liking, consumer ratings for the High and Moderate freshness groups averaged between 6 and 7 for all products on a 9-point scale, which ranges from 1 ("Dislike extremely") to 9 ("Like extremely"). This suggests that consumers generally "Like" these products. In Figure 4.6, for the Moderate freshness group, consumers rated the products over 6 as "like slightly," while for the High freshness group, they rated them over 7, as "like moderately." However, for the Low freshness group, the ratings were closer to 4, or "dislike slightly", for Linen Clean and Floral.

The Low fresh group shows that the Linen Clean and Floral samples received significantly lower liking scores compared to Tropical Fruity. As the freshness level increased in the Moderate and High freshness groups, the ratings improved for all samples, with no significant differences observed. This trend indicates that respondents that had lower scores on the freshness scale, tended to be more discriminative in terms of liking among products, and provided higher liking scores for products considered as less “fresh”. This means that Group 1 - Low Fresh could be identified as a freshness dislike group.

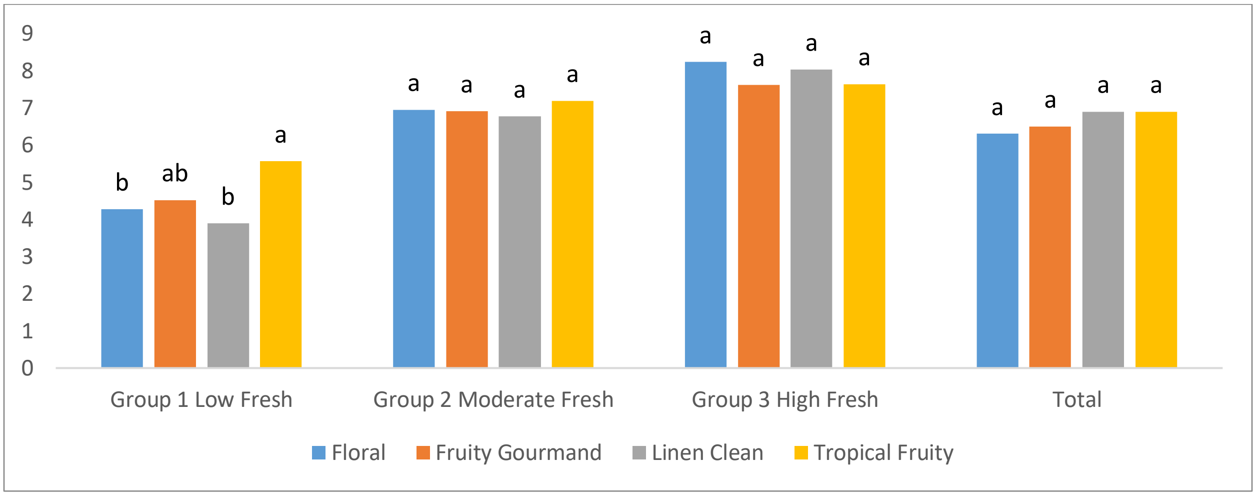

Figure 4.6: Comparison of freshness perception of overall liking ratings among groups. Ratings on 9 point-scale from 1: Dislike extremely to 9: Like extremely

To rate freshness intensity, consumers used a 7-point scale ranging from 1 (“None”) to 7 (“Extreme”). Figure 4.7 shows a comparison of freshness intensity ratings for samples across the three groups. Significant differences were observed among products for all of the groups. In the Low fresh group, Tropical Fruity and Fruity Gourmand received relatively lower scores, while Linen Clean and Floral scored significantly higher.

The Moderate and High freshness groups had higher ratings with less pronounced differences between the products when compared to the Low fresh group. Three levels of differences were observed among products in the Low fresh group, but only two levels in the Moderate and High fresh groups. This suggests that higher freshness levels are associated with a more consistent perception of freshness across products. However, tendencies were more consistent for freshness intensity compared to overall liking. Still, it is important to highlight, that the Low fresh group, still considered the Linen Clean product as having the highest “freshness” intensity. This suggests that this group is more susceptible to scent character and intensity vs. a perception of freshness. Moderate and High fresh groups value “fresh” qualities more than the Low fresh group.

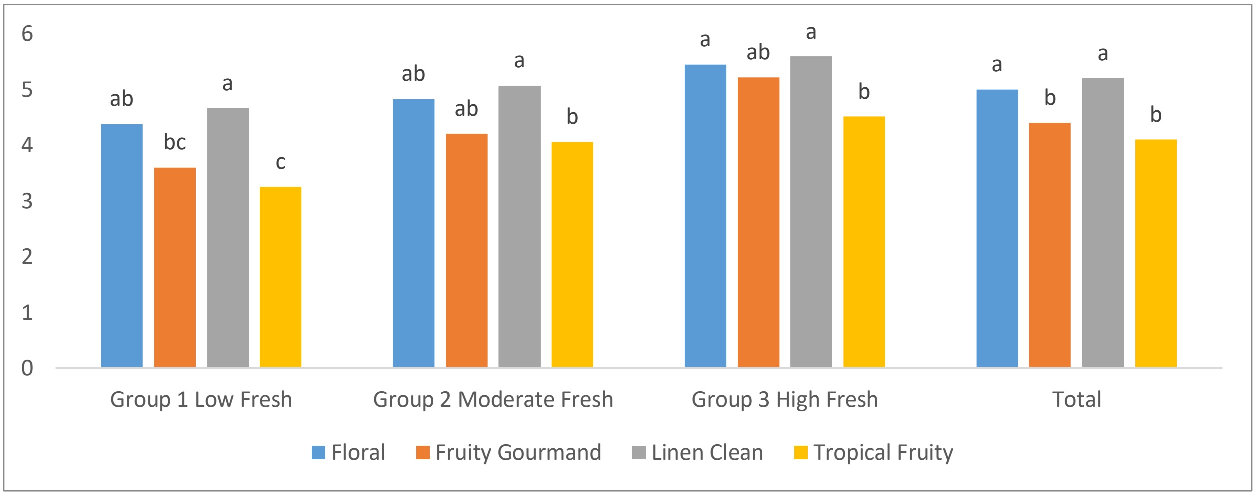

Figure 4.7: Comparison of freshness intensity ratings among groups. Ratings on 7 point-scale from 1: None to 7: Extreme

Product comparison by product related freshness scale

We again compared the products evaluated using the freshness scale, this time using the adjusted propensity scores. Results show that significant differences existed for only six statements, among the four air-care products evaluated, as shown in Table 4.7. All the statements were related to how the scent affects the environment. Specifically, the statements that showed significant differences among the products were: "The scent of this product adds to the cleanliness of my home," "The scent of this product brings a sense of renewal," "The scent of this product is long-lasting," "The scent of this product is uniquely seasonal," and "The scent of this product masks unwanted aromas." The Linen Clean product consistently received higher ratings for these attributes, suggesting that it is perceived as having the greatest impact on enhancing the environment. These findings imply that consumers associate freshness not only with “liking” a scent, but also with the scent's ability to positively alter their surroundings, such as by improving cleanliness or masking unwanted odors.

This pattern of results suggests that the perception of freshness is associated with environmental changes that consumers can directly perceive. The product with the Linen Clean scent, which received high ratings for attributes including enhancing cleanliness and providing a sense of renewal, implies the improvement of consumers' living environment would enhance their perception of freshness. In this context, freshness is not only an attractive scent, but also makes a space feel cleaner, more comfortable, and provides emotional uplifting. This implies that consumers relate the concept of freshness to scents that do more than just smell good. They expect scents that change their living space in a noticeable way, making it feel refreshed and more enjoyable.

Table 4.7: Product related freshness scale test results for four air freshener care scents products with using adjusted propensity scores

	Statements	Fruity Gourmand	Floral	Tropical Fruity	Linen Clean
Environmental Functionality	The scent of this product adds to the cleanliness of my home.	4.74 b	4.95 ab	4.91 ab	5.53 a
	The scent of this product contributes to good air quality.	4.45	4.61	4.61	5.05
	The scent of this product is long-lasting.	5.00 bc	5.51 ab	4.55 c	5.86 a
	The scent of this product has a clean character.	4.67	5.11	4.68	5.76
	The scent of this product brings a sense of comfort to my living space.	4.48	4.63	4.87	4.97
	The scent of this product promotes relaxation.	4.34	4.46	4.51	4.47
	The scent of this product can uplift my mood.	4.60	4.57	4.98	4.81
	The scent of this product creates a cozy atmosphere in my living space.	4.41	4.53	4.54	4.70
	The scent of this product brings calmness.	4.47	4.54	4.46	4.71
	The scent of this product brings happiness.	4.63	4.75	5.00	4.88
	The scent of this product masks unwanted aromas.	4.69 b	5.12 ab	4.75 b	5.38 a
Personal Productivity	The scent of this product enhances quality of life.	4.15	4.27	4.34	4.53
	The scent of this product enhances focus.	3.88 ab	3.96 ab	3.72 b	4.40 a
	The scent of this product boosts productivity.	4.08	4.00	4.12	4.50
	The scent of this product reduces stress.	4.23	4.27	4.53	4.49
	The scent of this product brings a sense of renewal.	4.21 b	4.45 ab	4.42 ab	4.85 a
	The scent of this product is crisp.	4.61	4.82	4.71	5.16
Contextual Associations	The scent of this product evokes positive emotions.	4.62	4.64	5.07	4.94
	The scent of this product is uniquely seasonal.	3.79 a	3.98 a	4.02 a	2.70 b
	The scent of this product adds excitement to my living space.	4.08	4.20	4.50	4.23
	The scent of this product contributes to overall well-being.	4.42	4.47	4.72	4.72
	The scent of this product contributes to a sense of safety.	3.57	3.86	3.64	4.05
Emotional Nostalgia	The scent of this product can bring back positive emotions from past experiences.	4.00	4.14	4.05	4.03
	The scent of this product can evoke nostalgic memories.	3.93	4.12	3.90	3.82
	The scent of this product rejuvenates my senses.	4.43	4.44	4.68	4.76

abc: Different letters within a row indicate statistically significant differences ($p < 0.05$) based on Fisher's test

Discussion

In this study, we used propensity scores to balance the effects of covariates including age, gender, and prior knowledge of the freshness concept. Results show that the product freshness groups—Low, Moderate, and High—are effective in capturing how consumers perceive freshness. The freshness scale worked well in distinguishing between these groups. The High and Moderate Fresh groups received higher ratings (between 6 and 7 on a 9-point scale), which means that these products are generally liked by consumers. In contrast, the Low Fresh group had lower scores. This suggests that the levels of overall liking are generally related to how products are rated using the product-related freshness scale. This scale was able to show these differences clearly, providing evidence of its effectiveness in measuring consumer experiences. We further explored and confirmed the relationship between freshness measured by the scale, freshness "intensity" and overall liking. This further demonstrated the effectiveness of the product freshness scale.

When looking at the specific products evaluated, there were differences in how consumers rated their freshness perception. Linen Clean consistently had higher ratings for statements related to scents and environment. This suggested that consumers treated the Linen Clean product as having an impact on improving freshness in their living space and emotional status. In contrast, Fruity Gourmand had a lower impact on freshness and its impact on the environment was less noticeable.

Freshness is also about how the scent changes the environment, not just how it smells. Statements including "The scent of this product adds to the cleanliness of my home" and "The scent of this product brings a sense of renewal" were rated significantly higher for Linen Clean compared to the other samples' scents. This implies that consumers perceive freshness as being related to making their space feel cleaner, more comfortable, and renewed. A scent that can mask unwanted odors or make a room feel cleaner has a big impact on how consumers think about freshness. Linen Clean did well because it was able to create these positive changes in the environment. The Floral product was somewhat close to the Linen Clean product for many of the ratings, suggesting that floral aromas can also be considered as “fresh”. Fruity products can still be liked by consumers but will have a lower impact on “freshening” the environment. This could have a more impactful effect long term, and more research is needed. Different types of consumers are also evident. A group of consumers that value scent character and intensity more than “freshness” will tend to like fruity aromas more than Linen or floral. More research will be needed to confirm these learnings.

Limitations

One limitation of this study is that, even though it was completed in real environments, it did not look closely at how specific factors like room size, ventilation conditions, or existing smells affect the perception of freshness. In the future, research could focus on these factors to understand how they change the way people experience scents. There is also a chance to study other things like humidity or temperature, which might change how fresh a scent feels. By exploring these factors, we can learn more about how freshness works in different settings and make products that work better in real-life situations. Additionally, more types of products and scents could be explored, as this study looked at only a few air care products. With limited product samples, some statements on the scale were not fully investigated, for example, “The scent of this product masks unwanted aromas”. Future research could include different types of scents, for example, woody, citrus, or herbal, and examine how they interact with environmental factors, such as different room sizes. Understanding these connections could help create products that work better across different spaces and meet a wider range of consumer needs. Another limitation was the duration of the study. This study was set up as a 5-day usage study, which may not be enough to have a full understanding of the effect of the scent on the home and at affecting more psychological factors in its users. A longer duration study with a more diverse pool of scents would be beneficial.

Conclusion

In conclusion, this study applied the features of a freshness concept to develop a product-related freshness scale. The statements on the scale are representative of the air care product's freshness characteristics. The scale effectively captured differences in consumer perceptions of various air care products and different freshness groups of consumers, which shows the importance of freshness in consumers' preferences. Fresh scents are not only appealing but are also involved in creating a positive change in the environment, including enhancing cleanliness, comfort, and renewal. Scents that make a space feel cleaner and more comfortable, like Linen Clean, are considered as more "fresh". This means that people value scents that can change how their home feels. These results suggest that future products should focus on scents that improve both the smell and the atmosphere of a room.

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Appendix A - Theoretic Background for Ising Model

The decision-making process of consumers, manifested in binary choices (0 or 1) regarding sensory attributes or associated perceptual and emotional characteristics of a product, can be effectively modeled using a graphical approach. In this model, nodes represent the individual features, while edges denote the interactions between them. The Ising model, with its ability to represent binary states and their interactions, could be a powerful tool for capturing the complex, interconnected decision processes inherent in sensory evaluations Banerjee et al. (2008); Ravikumar et al. (2010); Wainwright et al. (2008).

In the context of the CATA approach, a latent structure can be derived from the observed patterns of attribute selection (represented as binary variables, 0s and 1s, across all attributes). For example, this structure may manifest as a consensus profile, wherein a cohort of participants uniformly assesses all attributes of a product. We represent this latent structure, without loss of generality, by a vector x = (x1,x2,...,xp), where each xi (for i = 1,...,p) corresponds to the response given by a participant to a specific attribute. The tuple ($x^{1}, \boldsymbol{x}^{2}, \ldots, \boldsymbol{x}^{n}$) encapsulates the combination of attributes or terms explored in the CATA questions from n consumers.

We denote the inherent strength of an attribute as ti, which reflects the likelihood that the attribute can be independently identified. The interaction strength, s_{ij}, between two attributes (nodes), xi and xj, quantifies the degree of their interdependence. If two attributes are observed to be selected together (both 0 or both 1) more frequently than expected by chance, they exhibit positive interaction strength. Conversely, if the selection of one attribute as ”1” frequently coincides with the non-selection ”0” of another, the interaction strength is negative. Within the CATA data, this measure of interaction strength is instrumental in identifying attributes that are either complementary or mutually exclusive. A positive interaction strength, s, indicates that attributes are either commonly selected together or commonly not selected, suggesting a complementary relationship. A negative interaction strength, conversely, suggests that the selection of one attribute implies the non-selection of another, indicating a mutually exclusive relationship.

Based on these definitions, the overall strength, $R(x)$, of the underlying structure within the CATA data is defined by the equation:

$$R(\boldsymbol{x}) = \sum_{i=1}^{p} t_i x_i + \sum_{i=1}^{p-1} \sum_{j=i+1}^{p} s_{ij} x_i x_j$$

Here, the first sum represents the cumulative inherent strengths of the individual attributes, quantified by t_i for each attribute x_i. The double sum accounts for the interactions between every pair of different attributes, encapsulating the complex interplay of features within the dataset, with s_{ij} representing the interaction strength between attribute x_i and x_j.

Each sensory attribute x_i possesses an intrinsic strength. Based on this, we can construct a probability model to supervise the strength of each variable given the overall strength of the system. To ensure that the probabilities are positive and sum up to 1, we exponentiate the strength function. The probability model is then defined as follows:

$$P(\boldsymbol{x}) = \frac{e^{R(\boldsymbol{x})}}{Z} \tag{2.2}$$

where $Z = \sum_{\boldsymbol{x}} e^{R(\boldsymbol{x})}$ serves as the normalization constant ensuring that the probabilities sum to 1: $\sum_{\boldsymbol{x}} P(\boldsymbol{x}) = \sum_{\boldsymbol{x}} \frac{e^{R(\boldsymbol{x})}}{Z} = \frac{1}{Z} \sum_{\boldsymbol{x}} e^{R(\boldsymbol{x})} = \frac{Z}{Z} = 1.$

The full joint distribution of a particular variable x_i, in a system where variables may exhibit complex interdependencies, is not directly expressed as a simple closed form like P(x). Instead, we find the conditional distribution of xi, given all variables except xi, which denoted as $x_{\backslash i}$. The formula could be expressed as

$$P(x_i|x_{\backslash i}) = \frac{P(x_i, x_{\backslash i})}{P(x_{\backslash i})}$$

Using the strength function involving x_i, we write:

$$P(x_i|x_{\backslash i}) \propto e^{t_i x_i + \sum_{j \neq i} s_{ij} x_i x_j}$$

To normalize this to get a proper probability distribution, we sum over the two possible values of x_r:

$$Z_i = e^{t_i + \sum_{j \neq i} s_{ij} x_j} + e^0$$

The conditional probability then becomes:

$$P(x_i|x_{\backslash i}) = \frac{e^{t_i x_i + \sum_{j \neq i} s_{ij} x_i x_j}}{Z_i}$$

Since x_i is taking values in {0,1}, we can simplify further:

$$P(x_i = 1|x_{\backslash i}) = \frac{e^{t_i + \sum_{j \neq i} s_{ij} x_j}}{Z_i}$$

$$P(x_i = 0|x_{\backslash i}) = \frac{1}{Z_i}$$

These equations correctly represent how xi depends conditionally on the binary decisions of all other variables, capturing both its binary nature and the contributions from interactions and external strength. According to the conditional probability framework established in above model, it is naturally to use logistic regression to refine and quantify these relationships. By modeling the log-odds of a binary response directly as a function of other variables, logistic regression can be employed to estimate the parameters ti and sij. Under the assumption of sparse data, several efficient solving procedures have been developed to address the estimation problem. For consistency throughout the document, these procedures will be detailed in subsequent sections.

The details of the Sparse Ising model

According to the model we built above, we proposed a method utilizing logistic regression with a penalization term to analyze binary data. The method enhances variable selection robustness in binary data analysis by integrating stability selection with logistic regression, employing L1 norm regularization, known as the lasso penalty. This approach effectively addresses the challenges posed by the binary nature of CATA data, which includes the selection and regularization of variables to avoid overfitting while capturing the underlying patterns in respondent choices.

The estimation of an unknown graph structure, along with the associated parameters, is a crucial endeavor in network analysis. This process typically involves treating one variable, denoted as Xj, as the target response, and considering all other variables, X\j, as potential predictors. A logistic regression model is employed to elucidate the neighborhood structure surrounding Xj. Within this model, the intercept, tj, signifies the inherent tendency of Xj to adopt a value of 1 independently of its neighbors. The slope coefficients, sjk, measure the connection strength between the node j and its neighbors k.

To identify the neighboring variables of Xj, $\ell 1$-regularized logistic regression—commonly known as the lasso method—is utilized. This technique refines neighborhood selection by optimizing a convex function, which is both computationally efficient and effective in inducing sparsity in the coefficients, hence aiding in feature selection. The optimization function, indexed by observation i, is as follows:

$$\Theta^* = \arg\min_{\theta} -x_{ij}(t_j + \sum_{k \in V_{\setminus j}} s_{jk} x_{ik}) + \log(1 + \exp(t_j + \sum_{k \in V_{\setminus j}} s_{jk} x_{ik})) + \lambda \sum_{k \in V_{\setminus j}} |s_{jk}|$$

The formula presented embodies an $\ell 1$-regularized logistic regression optimization problem, targeting the estimation of parameters in a network. The first term of the formula encapsulates the negative log-likelihood for a logistic regression model, reflecting the fit of the model to the observed binary outcomes. It calculates the disparity between the predicted probability of the response variable being 1 and its actual value across all observations, with the aim of minimizing this discrepancy. Here, the vector θ comprises all parameters, including s_{jk} and t_j, while λ is the penalty parameter that encourages the model to maintain only the most influential predictors through the regularization term. The intercept t_j influences the baseline propensity of the variable to be 1, while the coefficients s_{jk} represent the strengths of the connections in the network. The second term is an $\ell 1$-regularization term, characterized by the parameter λ, which enforces sparsity in the model by penalizing the sum of the absolute values of the regression coefficients. This sparsity-promoting feature facilitates variable selection, leading to a parsimonious model that highlights only the most pertinent variables, which is particularly crucial in high-dimensional data contexts where the number of variables outstrips the number of observations. Together, these components work in concert to determine the most statistically significant network structure, yielding a model that is both interpretable and reflective of the underlying data associations.

The glmnet package in R is a practical tool for implementing this methodology, capable of evaluating a spectrum of up to 100 values for the penalty parameter, λ. The result is a comprehensive suite of possible neighborhood sets, from which the most likely network structure is deduced.

Upon establishing the logistic regression model, each variable in the dataset undergoes an iterative analysis, successively serving as the response variable against all other predictors. The glmnet package aids this iterative fitting process, facilitating an in-depth exploration of inter-attribute relationships, their direct and indirect linkages, and their effect on an attribute's selection probability.

Model optimization, including the choice of regularization strength λ, adheres to the kfold cross-validation, typically with $k = 5$. This process, implemented through the cv.glmnet function, involves dividing the data into five subsets or folds. The model is then fitted on four of these folds, with the remaining fold used as a test set. This process is repeated such that each fold serves as the test set once, ensuring that each data point contributes to both training and validation. For each value of λ cv.glmnet calculates the prediction error on the validation set, typically measured as mean squared error. The optimal λ is selected as the one that minimizes the average cross-validation error across all folds. Additionally, cv.glmnet provides a measure of error variability and may suggest a λ that trades off minimal error for increased model simplicity, enhancing model interpretability and robustness. After applying this procedure to all variables, we assess the relationship between each variable X_j and the set of other variables $X_{\setminus j}$. To enhance the reliability of our findings, we employ the stability selection procedure, which is famous in graphical selection model.

The stability selection procedures will be encapsulated with above optimization procedures to define the final set. The procedure is to repetitively apply above procedures across numerous subsamples of the data Meinshausen and Buhlmann (2010); Shah and Samworth (2013). In each iteration, the model is fitted on a different subset of the data, and the selection of variables (those with non-zero coefficients) is noted. A variable's selection frequency is computed by tallying how often it appears as significant across all the subsamples. The final set of variables is determined by applying a frequency threshold—typically, a variable must be selected in more than half of the subsamples to be included in the final model. In this study, we generated 100 subsamples, each representing 70% of the original sample size, for analysis. This process effectively filters out variables that are inconsistently selected, thus minimizing the risk of including predictors that might only seem important due to random variation or specific sample biases. Where feasible, these complex relationships are visualized through a network graph, bolstering interpretability and providing an expansive view of the data structure.

By employing logistic regression with lasso regularization and stability selection, this method advances the analysis of binary data by providing a robust framework for understanding the complex interplay of attributes in influencing respondent choices. The methodology's strength lies in its ability to reduce model complexity, enhance interpretability, and reveal significant patterns and relationships within the data, offering valuable insights for research and practical applications in consumer behavior analysis.

Proof of MRF

The paragraphs offer a validation that in Markov random fields, higher-order relationships among variables can be effectively represented as pairwise interactions through the introduction of additional auxiliary variables. The details of the proof were have been thoroughly discussed in Wainwright et al., 2008. Here we show the major parts. Consider an MRF with a set of variables $\{x_i\}$, where each variable x_i can take a value from a finite set. The joint probability distribution of all variables in the MRF with higher-order interactions is given by:

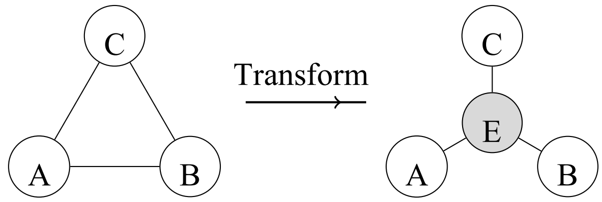
$$P(X_1, X_2, \ldots, X_n) = \frac{1}{Z} \exp\left(\sum_{\alpha} \Phi_\alpha(X_\alpha)\right)$$

where α indexes the subsets of variables that have interactions, Φα represents the higherorder potential functions, and Z is the normalization constant. To transform this model into one that only involves pairwise interactions, we introduce auxiliary variables {Aα}, each associated with one of the higher-order interactions Φ_α. The goal is to construct a new model with joint probability distribution:

$$P'(X_1, X_2, \ldots, X_n, A_1, A_2, \ldots, A_m) = \frac{1}{Z'} \exp\left(-\sum_{\langle i,j\rangle} \Psi_{i,j}(X_i, X_j) - \sum_{\alpha}\sum_{i\in\alpha} \Psi_{i,\alpha}(X_i, A_\alpha)\right) \tag{6}$$

where Z′ is the new normalization constant, and Ψi,j represents the new pairwise potentials. The equivalence of the original and transformed models is demonstrated by showing that for any configuration of $\{X_i\}$, integrating out all configurations of $\{A_\alpha\}$ from P ′ recovers P. The key to this proof lies in the careful design of the pairwise potentials Ψ to ensure they correctly encode the higher-order interactions.

This process shows that any higher-order interaction in an MRF can, in principle, be converted into an equivalent set of pairwise interactions by introducing auxiliary variables and appropriately defining new pairwise potentials. This approach allows for the application of efficient inference and learning algorithms developed for pairwise models.



Appendix Figure A. 1: Simplified interactions with an auxiliary node E.

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Epskamp, S., Maris, G., Waldorp, L. J., & Borsboom, D. (2018). Network psychometrics. *The Wiley handbook of psychometric testing: A multidisciplinary reference on survey, scale and test development*, 953–986.

Appendix B - Focus Group Discussion Guide

INTRO (5 min): Hello, thank you for taking the time to come and talk to us today. I will be your moderator for the next 90 minutes. Today we will be talking about your perceptions and opinions about air fragrances and the concept of freshness.

FACILITY SETTING: Mention mics, observers through video, and taping.
This session is being recorded so that I can go back and review what was said, not who said it. That will help me write a more accurate report and no identifiable information will be provided at any time. Your participation today is confidential. I have Gongshun here in the room who will be helping me make notes of today's discussion.

You are free to get up and excuse yourself to go to the restroom or get water. I ask that only one person should be up or out at a time, so we do not disrupt the normal flow of this group.

I have a few guidelines I would like you to follow for a more productive research session

1. Please only talk one at a time. Remember that this session is being recorded.
2. Talk as loudly as the moderator does so that everybody, including people listening to the recording, can hear.
3. Avoid any side conversations. All comments are important for the research, so if you have something to say, please share it with the group.
4. Work for equal "air time". I want everybody to talk and share your opinions, no one talking too much or too little.
5. I encourage discussion. Allow for different points of view, there are no wrong answers, and I WANT TO BE VERY CLEAR ABOUT THIS.
6. Say what you believe, that is why you are here, even if no one agrees with you, it is fine to disagree.
7. I am aware that I have an accent. If there is anything you do not understand, please let me know and I will be happy to repeat.

Rapport, 5min

To begin, I would like to know a little more about you. Please tell me:

- First name
- Who lives with you at home?
- Introduce one of your favorite air fragrance products at home you use most often? What is about that product that you like.

Homework Review, 15min

- Describe your homework to the group.
- Probe about emotions and specific terms related to freshness
- Probe about color, images, etc.

Term Generation, 20min

Let's talk about the concept of "freshness" and air fragrances. Use the post-it notes to write down words that represent "freshness" to you. Use no less than 5 post-it notes, one per word.

- Probe, what is freshness to you?

Describe products you have experienced before that made you experience "freshness" (it can be products you have smelt, purchased, used, etc.)

- Probe on when, where and why.
- Probe about trigeminal effects (tingling, cooling, warming, tec.) related to freshness.

Product grouping activity, 40min

Individual Task 20min

Overall Instructions:

Next, we would like to do a mapping exercise on the products we prepared for you. You will need to group the products on the white paper in front of you, based on the different levels of freshness perception you may have with them. For this task, there are no right or wrong answers, and we are interested in your spontaneous mapping of the products. Each of you will have 12 products to work with, please go through them carefully, take your time.

More mapping instruction:

Place the products on the paper according to the strategy that two products placed closer to each other are more alike in delivering the freshness perception than two placed further apart.

- Please use the whole space of the worksheet.
- The criteria for how to separate the samples just must make sense to you.
- Again, there are no right or wrong solutions. Do you have any questions?
- Use words to describe the dimensions/groupings, etc.

Probing after the task, 20min

Go around the room for each participant to introduce their map

- What is the main characteristic differentiating your products?
- What is the second most important characteristic differentiating your products?
- If you were to characterize a product as high in “freshness”, where in the map where you place it?
- If you were to characterize a product as low in “freshness”, where in the map where you place it?
- What makes you feel that way? Any impact from their value set, lifestyle, or demographic? Background?
- Any emotional/affective terms related?

Wrapping up, 5min.

Appendix C - Focus Group Homework

Think about ANY (Air Care) product that you have experienced in the past that made you feel/think/experience FRESHNESS. By air care product we mean any products used to alter the aromas in a room. What did you smell? How did you feel? Prepare a collage with pictures taken from internet printouts, magazines, newspapers, drawings, sketches, etc. to illustrate these questions.

Please follow these guidelines to prepare this collage. PLEASE READ THIS CAREFULLY.

1. Grab four standard pieces of paper (A4, 8.27*11.69 inches paper) and tape them together (sample below). This will be your worksheet You may use a different material for your worksheet (cardboard, pasteboard, etc.). However, the dimensions of the final worksheet should be comparable. Slightly larger worksheets are acceptable.

2. To prepare the collage: In your new worksheet, glue or tape pictures printed out from the internet, cut outs from magazines, newspapers, or any printed media. Drawings/sketching or a combination with pictures is also acceptable.

3. These pictures should represent the products and your emotions, feelings, or the state of mind you experience when you are purchasing, preparing, or using the air care products. Be creative, the pictures could be anything! a. Minimum of 9 pictures b. Maximum of 18 pictures

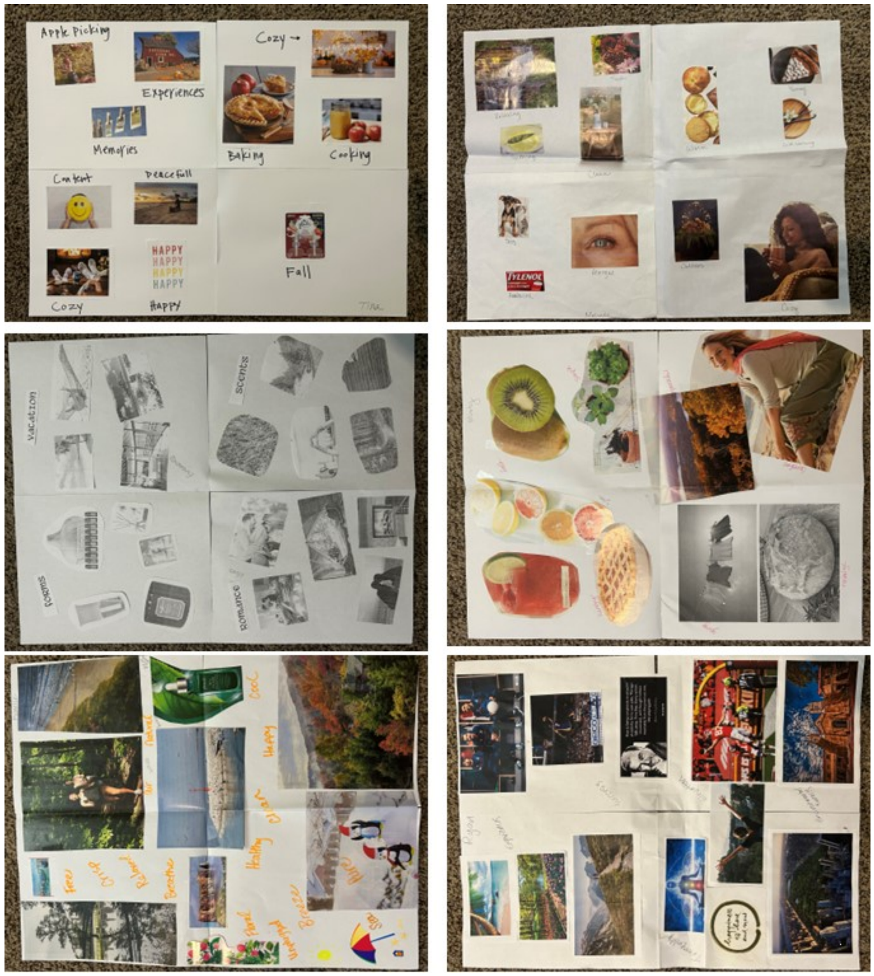
4. How you organize the pictures in the worksheet is up to you, you can scatter them across the paper, or you can organize them by categories, or anything you see fit.

5. Please also use single words to describe the product characteristics that made you feel that way or explain your feelings. <u>Full statements are not acceptable.</u>

Please bring the hard copy of your homework with you the day of the group! Pictures on your phone do not qualify! This will be checked at the door before entering the room. Only participants who bring their homework will be allowed into the session.

Please do not wear any strong perfumes/aroma on the testing day. If you are wearing strong perfumes/aromas, you may not be allowed to participate

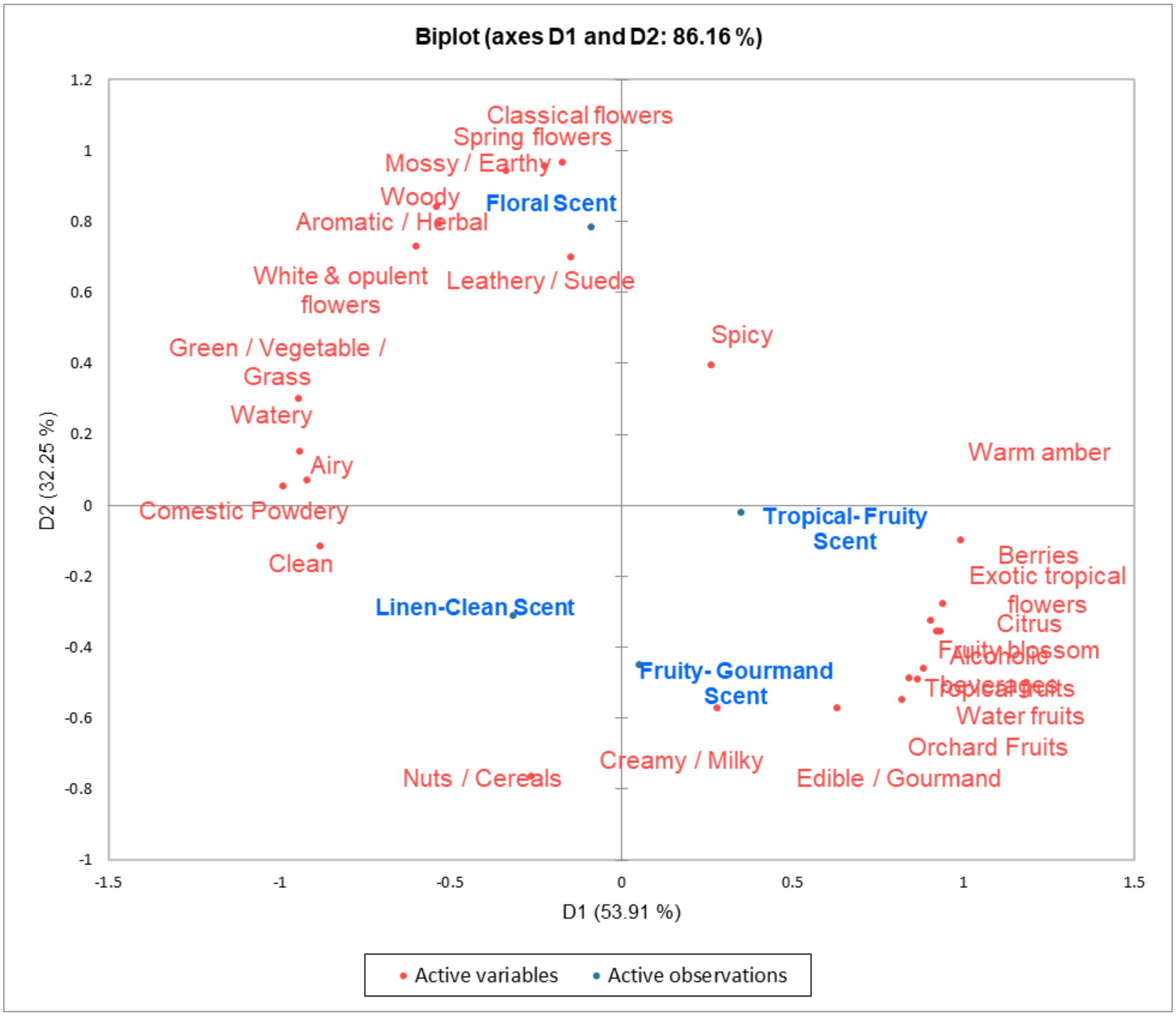
Appendix Figure C. 1: Focus group homework 1



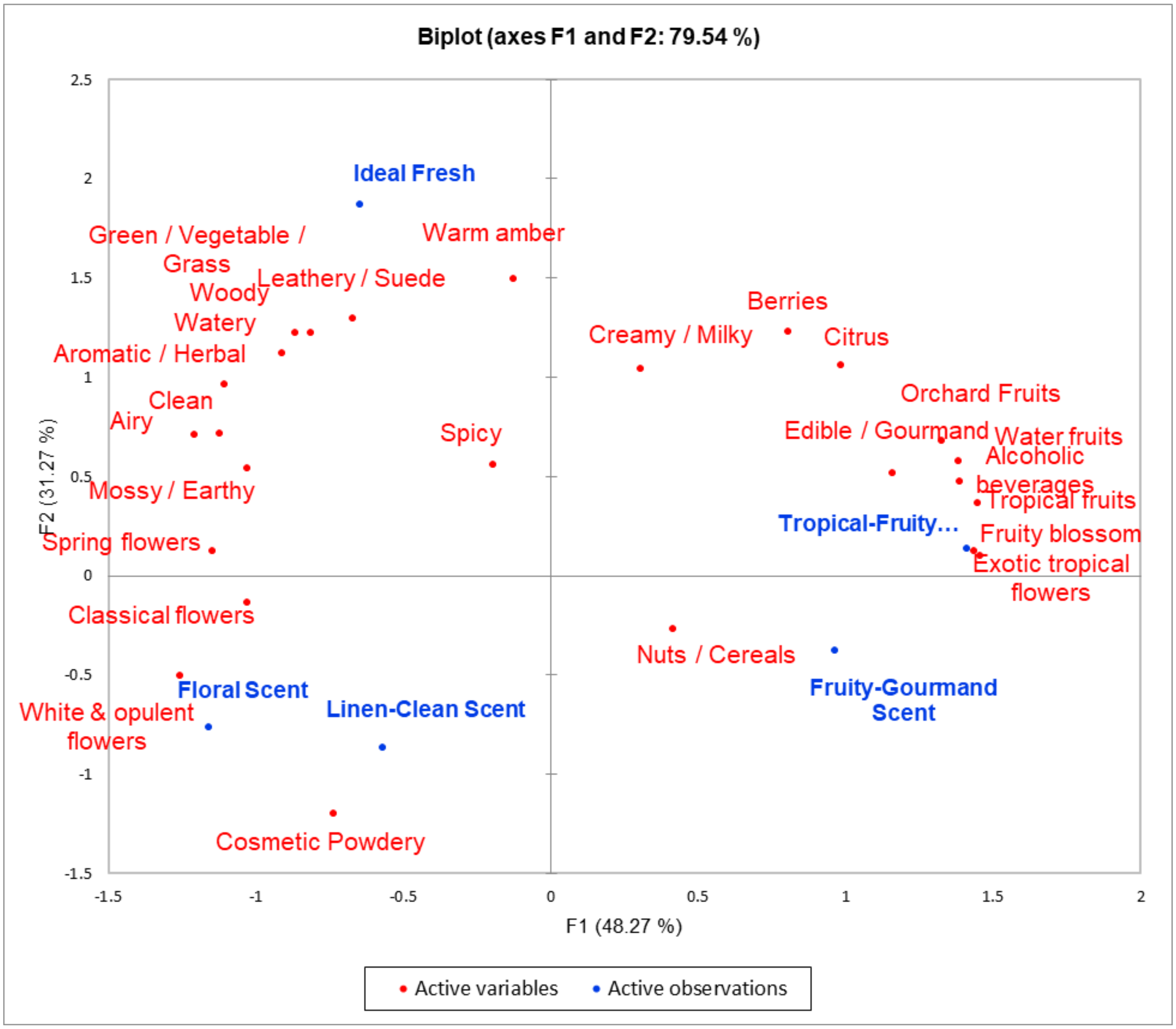
Appendix Figure C. 2: Focus group homework 2

Appendix Figure C. 3: Focus group homework 3

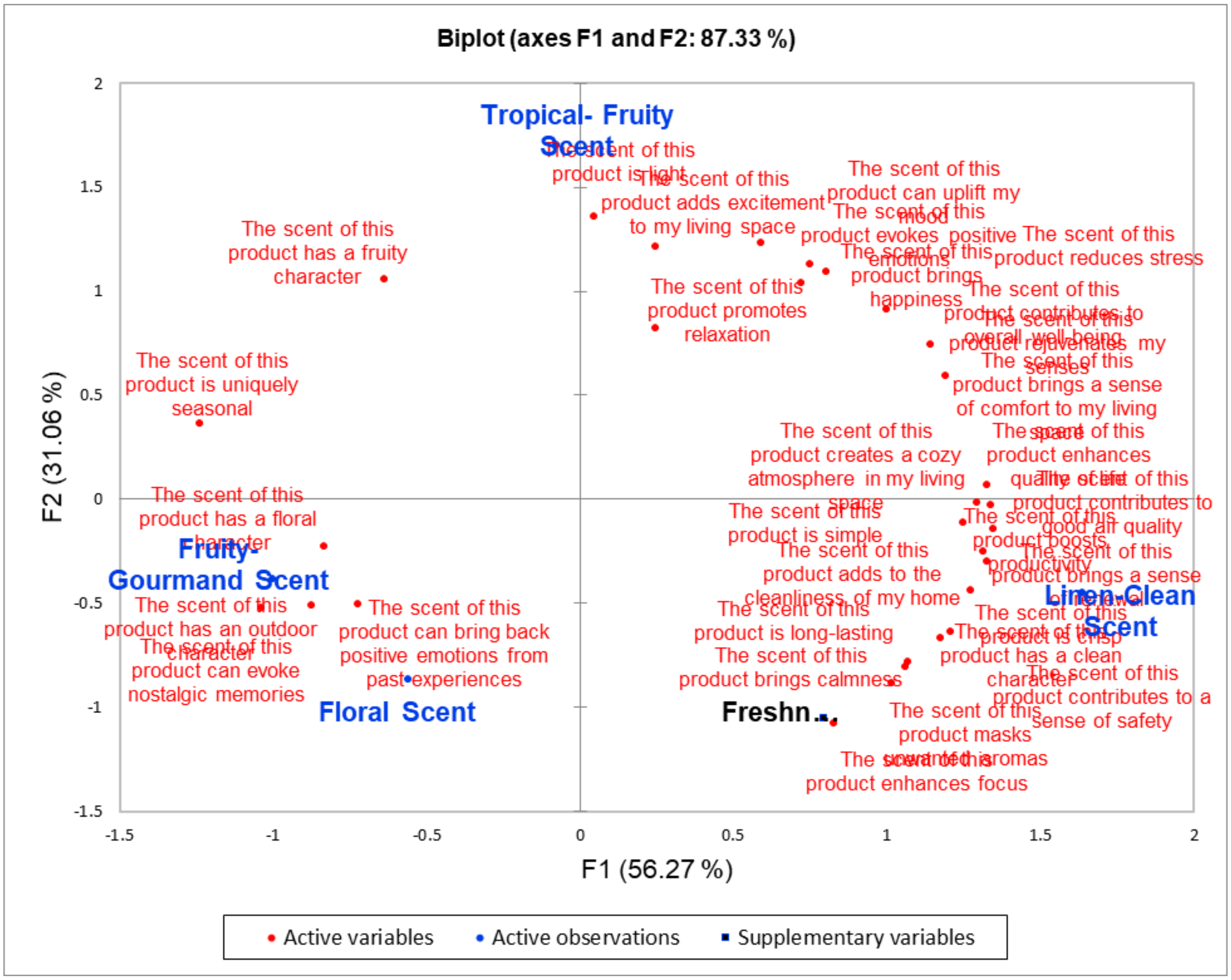
Appendix D - Supplementary Information



Appendix Figure D. 1: Aroma characterization - CATA frequency plot



Appendix Figure D. 2: Aroma characterization - CATA frequency plot with ideal fresh sample



Appendix Figure D. 3: PCA biplot- ALL statements