Visualization of Actionable Food Knowledge: Lessons from the Development of the Food Balance Lunchbox

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Abstract

Background The Food Balance Wheel, the current Korean food-based dietary guideline, fails to convey personalized recommendations on serving size, proportionality between five food groups, and fluid intake. An alternative design, the Food Balance Lunchbox, was designed in the CCW Treemap format for more effective visualization of personalized calorie intake and proportionality. Labelled photo icons exemplify serving sizes in weight and volume. Text information further clarifies the proportionality in percentages and recommended fluid intake in cups.

Methods In a randomized trial with 200 participants, the two designs were tested. Part I compared communication performance in terms of Moderation, Diversity, Proportionality, and Hydration tasks. Part II collected ratings on Interestingness, Aesthetics, and Proportionality Visualization for each design.

Results Part I scores were higher for Lunchbox (Mdn = 19) than Wheel (Mdn = 5) at $p < 0.001$ in total, and for each of the four tasks. Qualitative data confirmed the participants' appreciation of labelled photo icons that enhanced information granularity on serving size. Part II scores, however, were higher for the Wheel design in terms of Interestingness and Aesthetics, while Proportionality Visualization scores were similar between the designs. The Lunchbox design was perceived as dull and too crowded with information.

Conclusions The Food Balance Lunchbox, while more informative than the Food Balance Wheel, needs improvements. In future studies, an interactive version will be developed with contextual presentation of information, as well as a customizable food list and enhanced proportionality visualization.

Keywords Information Design, Food-Based Dietary Guidelines, Frequency Visualization, Information Granularity

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1. Introduction

In South Korea, the percentage of overweight cases (BMI ≥ 25) has risen to 34.8% in 2016, and extreme obese cases (BMI ≥ 30) amount to 5.5% (Lim, 2018). As obesity is linked to an increased risk of lifestyle-induced diseases, diabetes, e.g., the government published the Dietary Reference Intakes for Koreans (KDRIs) as a preventive measure. KDRIs communicates personalized information on moderation, diversity, proportionality, and hydration (Table 1), according to each person's age, gender, height, weight, and physical activity level.

Table 1 Information requirements for food-based dietary guidelines

	Moderation–Personalization	Diversity	Proportionality	Hydration
Personalized daily calorie needs	✓			
Five food groups and items in each group (Grains, Meat, Vegetables, Fruits, Dairy, Fat and Sugar)		✓		
Serving sizes of food	✓		✓	
How much to eat from each food group	✓		✓	
How much to eat from each macronutrient (Carbohydrates, Protein, and Fat)	✓		✓	
Personalized daily fluid needs				✓

A Type						
Kcal	Grain	Meat, fish, eggs, beans	vegetables	Fruits	Milk, Dairy products	Oil, sugar
1,000	1	1.5	4	1	2	3
1,100	1.5	1.5	4	1	2	3
~	-	-	-	-	-	-
2,600	3.5	5.5	8	4	2	8
2,700	4	5.5	8	4	2	8
2,800	4	6	8	4	2	8

* Pattern A: 1,000 ~ 2,700 / Pattern B: 1,000 ~ 2,700 (Milk·Dairy products 1 times recommended)

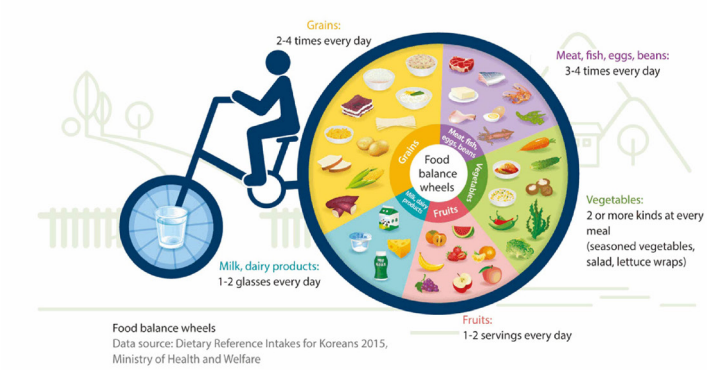

Figure 1 (a) The KDRIs dietary patterns table, and (b) the Food Balance Wheel

The KDRIs book—first published in 2005 and revised twice in 2010 and 2015—consists of chapters on energy and macronutrients, vitamins, minerals, and 37 calorie cases of recommended dietary patterns (Fig. 1a, Jung et al., 2015, pp. 958-959): Pattern A has 19 cases for children and adolescents who need two servings of dairy products daily, and Pattern B shows 18 cases for adults. For each case, recommended servings from five food groups differ. KDRIs, however, is a 55-page scientific document; it is not easy for adults to thoroughly study the book, or for children to comprehend ambiguous scientific terms in the

book. For that reason, the Food Balance Wheel—식품구성자전거 in Korean—is developed as visual food-based dietary guidelines (FBDG), to summarize and inform what consumers practically need to know for healthy eating (Fig. 1b, Jung et al., 2015, p. 919). The design exhibits a bicycle rider; the front wheel contains a cup of water, and the rear wheel visualizes proportionality between five food groups. The bicycle metaphor emphasizes the concept of balance: a balanced diet, and the balance between healthy eating and physical activities.

The current design of the Food Balance Wheel, however, is ambiguous and misleading. The recommended number of servings from food groups are not personalized; it is written in range values, which is an ambiguous direction for consumers. Serving sizes of food are unknown. A cup of water is attached to the front wheel, but exactly how much water to drink is not specified. A detailed examination continues in Section 2.2.

Such findings led us to develop an alternative FBDG with improved design and content, to impart personalized and actionable food knowledge for the consumer's better food behavior. Healthy eating is an abstract concept. Translating it into comprehensible terms and concrete directions will change the consumer's perceived behavior control, i.e., "people's perception of the ease or difficulty of performing the behavior of interest" (Ajzen, 1991, p. 183). For example, *eat three Grains servings daily* can be further explained with specific examples: *two slices of bread* or a *210 g of rice-bowl*. Previous studies find a positive linkage between knowledge and healthy behaviors. Ghannadi et al. (2016)'s study with 117 Type 2 diabetes patients found a significant correlation between the patients' knowledge levels and self-care activities. Jang (2010) concluded that students with higher nutritional knowledge spent more extended time for eating, and chose healthier options such as fish, eggs, or beans. This study identified the problems of inaccurate and insufficient information in the Food Balance Wheel and proposed an alternative FBDG design. Two FBDG designs were tested using an online questionnaire, concerning (1) performance in communicating moderation, diversity, proportionality, and hydration information, and (2) design properties of being interesting, aesthetic, or effective in proportionality visualization. The study participants' comprehension scores, design ratings, and comments were collected for the analysis.

A notable problem in the Food Balance Wheel is the proportionality visualization between five food groups that appears to be distorted; besides, proportionality should vary in each calorie case, but the current design presents it in one pie chart with fixed values. In search of a better frequency visualization format, the authors reviewed FBDG designs from countries around the world for design and content inspirations. Findings are reported in the next section.

2. Literature Review

2. 1. A Global Review of FBDGs

Visualization of complex data allows for an intuitive understanding of the data, as diagrams elucidate the conceptual structures of information (Oxman & Planning, 1997). So do FBDG designs from countries; they reflect the agricultural production system, culinary tradition, and lifestyle-induced health issues specific to each country. A global review of food-based dietary guidelines (Appendix A) sheds light on the differences in format and contents.

Format: 67% of the 34 European FBDGs are in the pyramid format. The pie chart is the second popular choice, while the column chart and other unique designs are occasionally used (Montagnese et al., 2015). Perelman (2011) reported a controversy caused by the widely used pyramid format in the U.S.; the top section food can be either the highest in nutrition or the smallest to be consumed. Recently developed German 3D Food Pyramid (Oberritter et al., 2013) clarified it with red-green spectrums that indicate less

healthy items were placed higher. Japanese cleverly dodged this issue with an inversely conical pyramid where the smallest space was placed at the bottom ("Japanese Food Guide Spinning Top," n.d.) The pyramid format, however, suggests fixed proportionality—when all tier heights are equal, the top three tier area ratio is fixed to 1:3:5—thus designing FBDGs in the pyramid format requires more caution. Pie charts were reported to be preferred to the pyramid format in other studies. While the British FBDG was developed, Hunt, Gatenby, and Rayner (1995) tested ten combinations of design variables: formats (pyramid, flat pie chart, or tilted pie chart), color schemes (multi-color or single-color), and presentation styles (color photos or line illustrations). The study concluded that while the most preferred design was the tilted pie chart with photo icons, design was not significantly correlated to communication performance, as much as the study participants' gender, age, or socio-economic status did.

Moderation/proportionality: The U.K. Eatwell Guide (Public Health England, 2018) addresses the gender differences in recommended daily calories, and Japanese Food Guide Spinning Top (Japanese Ministry of Health, Labour and Welfare, 2010) spells out the food group proportionality, recommended number of servings, and serving sizes.

Diversity: FBDGs present food groups and food items in the groups on different abstraction levels. American MyPlate (U.S. Department of Health and Human Services and U.S Department of Agriculture, 2015) and Hungarian House of Healthy Nutrition (Rodler, 2004) only present food group labels, while German 3D Food Pyramid (Oberritter et al., 2013), Australian Guide to Healthy Eating (2013), and the U.K. Eatwell Guide (Public Health England, 2018) show tangible examples in each group. The Finnish Plate Model (Fogelholm et al., 2014) more specifically shows a typical public lunch catering meal of potatoes, fish, and vegetables served on a plate to contextualize the information better. The food examples are presented in either illustrations or photos. Hunt et al. (1995) tested two presentation styles (color photos or line illustrations) and found photo icons presented in the tilted pie chart were preferred the most. Talati et al. (2017) also confirmed Australian consumers' preference for the circular pie chart and photo icons to other designs. Subjects in various age groups preferred realistic photo images of food to cartoon-style drawings, because "you can actually tell what they are" (p. 173).

Hydration: The German 3D Food Pyramid (Oberritter et al., 2013), Japanese Food Guide Spinning Top (Japanese Ministry of Health, Labour and Welfare, 2010), the U.K. Eatwell Guide (Public Health England, 2018), Australian Guide to Healthy Eating (2013), and Finnish Plate Model (Fogelholm et al., 2014) mention hydration as an important part of healthy eating.

The review of FBDGs inspired the authors to explore various frequency visualization formats other than the pyramid or pie chart, as well as photo icons in place of illustrations for accurate descriptions. A detailed review of communication problems in the current Food Balance Wheel design, including the misleading proportionality visualization of the rear wheel, continues in the next section.

2. 2. Food Balance Wheel: Communication Problems

Functionally, the Korean Food Balance Wheel (Fig. 1b) is two pie charts that illustrate the concepts of diversity, proportionality, and hydration. In Hong (2013)'s study with elementary school students, and the authors' unpublished qualitative study with college students, the current design failed to clarify the following information.

(a) Personalization-moderation: the personalized recommendation of daily calorie intake. Being a static image, the Food Balance Wheel fails to individuate 37 dietary patterns (from 1000 kcal to 2700 kcal). Servings in each food group are written in range values (Fig. 1b, "Eat 2-4 times a day from the Grains group"), which can be ambiguous and arbitrarily interpreted. From the information, some female elementary school students thought they needed three Grains servings daily (Hong, 2013), but KDRIs recommends only 2 or 2.5 Grains servings for them.

(b) Proportionality: the recommended food intake from each food group. The current rear wheel design is misleading in two aspects.

- What slices are proportional to is not clarified: the number of servings, weight of food, volume of food, or calories. Nonetheless, the slices appear to indicate how much to eat from each group. The Vegetables slice is only slightly larger than the Meat slice. In fact, the college students participated in the authors' unpublished study have mistaken it as the recommended vegetable–meat consumption ratio. They also thought protein should take up about 30% of the daily calorie intake, while the expert recommendation is between 7-20% (Jung et al., 2015, p. 927).
- Arranging order: In the rear wheel, slices are arranged in the order of Grains, Meat, Vegetables, Fruits, and Dairy. The Meat slice comes before Vegetables, and it led some male elementary students thought they should eat more meat than vegetables following the order (Hong, 2013).

(c) Hydration: recommended daily fluid intake. The Food Balance Wheel does not clarify how much water to drink and whether the amount refers to fluid from all food and beverages or just plain water. Recommended fluid intake is 1900 ml for girls and 2100 ml for boys (Jung et al., 2015, p. 213), while Hong (2013) 's study participants thought to drink 500-1000 ml of water daily. The two wheels in the Food Balance Wheel cause unnecessary misunderstanding. Some college students participated in the authors' unpublished qualitative study interpreted that *"The 12 front-wheel slices are the cups of water you need to drink"*, *"The rear-wheel slices are the cups of water you need to drink, one per each food group",* or *"The front and rear wheel diameters ratio is the water to food ratio."* They also shared a common belief of *"2000 ml of water daily"* that they learned from various news media.

3. Alternative Design: Food Balance Lunchbox

In response to the above-mentioned problems, the authors developed an alternative FBDG in the constant-column width (CCW) treemap format, the Food Balance Lunchbox (Hahn & Oh, 2019). Design-wise, it is a five-section square looking similar to pre-packaged meals sold in Korean convenience stores. Following design requirements were considered.

3. 1. Proportionality Visualization

Though widely used for frequency data visualization, empirical evidence speaks against using the pie chart for the quantity/proportion comparison task that requires a series of cognitive processes. A pie chart is complicated as a shape thanks to its curved and straight lines; the different orientations of pie slices add more cognitive difficulties of mentally rotating them for comparison (Cleveland and McGill, 1984, as cited in Huestegge & Pötzsch, 2018). Simkin and Hastie (1987) compared the pie chart that requires angle assessment, the simple bar chart that requires position comparison along a common scale, and the divided bar chart that requires length comparison. For the proportion-of-the-whole estimation task, the pie chart was as accurate as the simple and divided bar charts. For the task of comparing two parts of the same graph, however, the pie chart was the least accurate among them. The results were attributed to the position information in the simple bar chart that facilitated the anchoring cognitive process better than length or angle. According to Mackinlay (1986, as cited in Kilb & Jansen, 2016), position and length encode quantitative values more accurately than angle and area. As a pie chart visualizes information with angle and area, it is less effective than alternatives that use length or position, such as bar charts (Kilb & Jansen, 2016, pp. 196-198). Siirtola (2019, pp. 151-156) concluded that the pie chart was slower and less accurate than the stacked bar chart, especially when the difference between the elements was small.

Contrarily, Huestegge and Pötzsch (2018) reported the superiority of the CCW treemap to the pie chart in proportion and comparison judgment tasks. The CCW treemap combines the benefits of the column, pie and treemap charts altogether: (1) the ease of one-dimensional length comparison of a column chart, (2) visual cues such as a quarter, a half in a pie chart (p. 213) and (3) the high space efficiency of a treemap that allows for labelling inside the chart (Fig. 2).

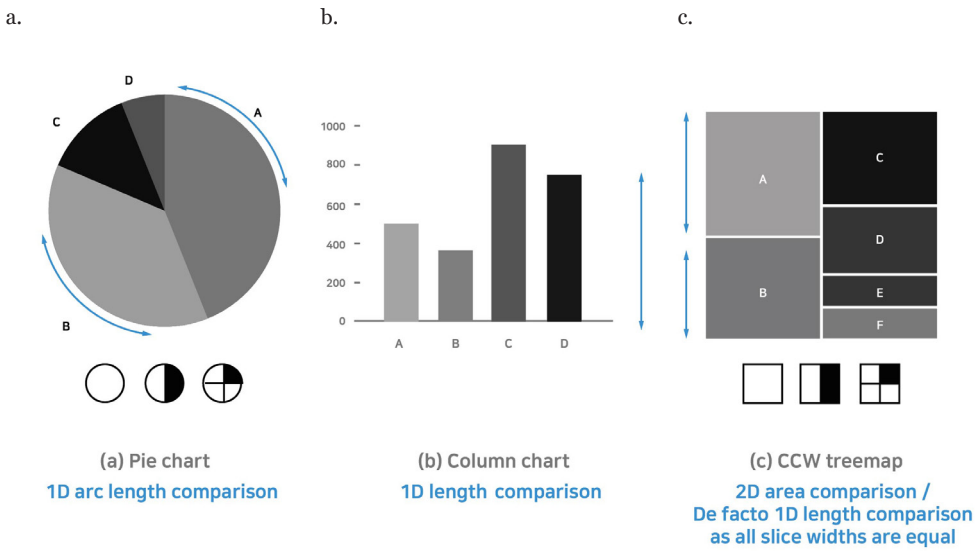

Figure 2 A comparison of the pie chart, column chart, and CCW treemap

Such findings inspired us to design the new FBDG in the CCW treemap format (Fig. 3). The slices were made proportional to the weights of five food group representative items (a rice bowl for the Grains group, e.g.) for the following reasons:

- Recommended dietary patterns are written in the number of servings, but servings in food groups differ in calories: a Grains serving is 300 kcal, a Meat serving is 100 kcal, while a Vegetables serving is 15 kcal. For consumers who do not know this, visualizing proportionality based on the number of servings can be misleading.
- The proportionality between food groups is best calculated and visualized in calories, but Zhou, Bell, Nusrat, Hingle, Surdeanu, and Kobourov (2018) reported that the consumer's calorie estimation success rate is as low as 5 out of 20 correct guesses. Weight or volume information, meanwhile, is a more tangible and memorable cue for serving size estimation.
- Accurate volume measurement, comparison, or calculation, however, are difficult for irregular forms of food, e.g., ribs or salad, while weighing is feasible for most food items.
- Representative items in five food groups were selected because servings in a food group differ in both weight and volume: 100 g of tomatoes or 30 g of mushroom, e.g.

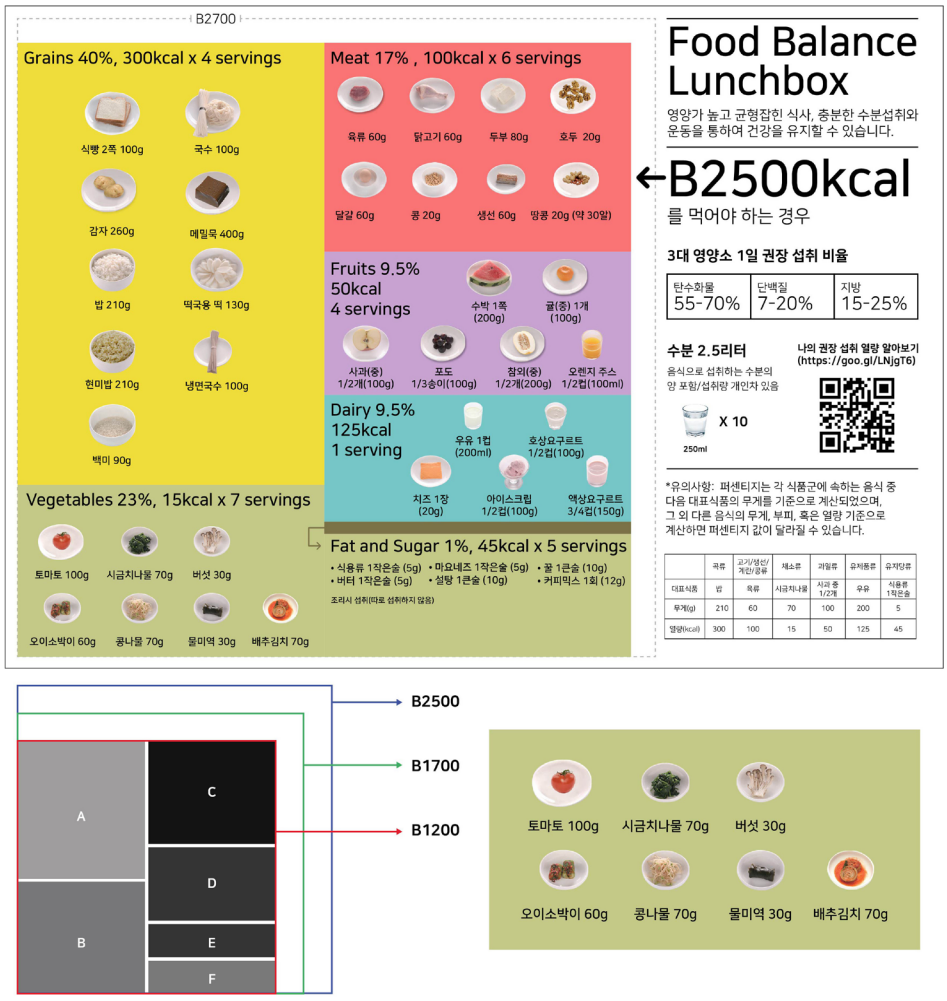

Figure 3 The Food Balance Lunchbox with labelled photo icons

3. 2. Scalability for Moderation–Personalization

CCW treemap slices in the Food Balance Lunchbox are scaled up or down, to visualize quantitative differences between 37 calorie cases. In Fig. 3, B1200, B1700, and B2500 cases were drawn in different sizes.

3. 3. Serving Size Description with Photographic Food Icons

The authors hypothesized that repeated exposure to accurate serving sizes enables people to estimate better in the eating context. Robinson et al. (2016) reported that repeated exposure to a large portion (not serving) sizes affect what consumers think a normal-sized food portion. Spanos, Kenda, and Vartanian (2015) concluded that informing consumers on how many servings were in the food portion reduced their food consumption. The Food Balance Lunchbox design accurately portrays serving sizes with photos to the last step of classification (rice, brown rice, or multigrain steamed rice, e.g.) Labels (“Tomato, 100 g”) clarify the serving size in weight, while photos illustrate it in volume. Miscategorizable items were clarified; for example, walnuts rich in both fat and protein were intentionally listed up in the Meat group.

3. 4. Hydration Clarified in the Text

The confusion caused by the water cup and two wheels in the Food Balance Wheel was resolved with a text description of recommended daily fluid intake—the amount including indirect water intake from food and beverages—added on the right side.

4. Evaluation Study Design

4. 1. Research Questions and Hypotheses

A quantitative study of comparing the Food Balance Wheel ("Wheel") and the Food Balance Lunchbox ("Lunchbox") was conducted with two research questions.

(1) How does the Lunchbox design compare to the current Wheel design in communicating moderation, diversity, proportionality, and hydration information, according to Korean males in 30s?
(2) How does the Lunchbox design compare to the current Wheel design in interestingness, aesthetics, and proportionality visualization, according to Korean males in 30s?

The first question investigated the quantified performance of the Lunchbox design in communicating four areas of food knowledge. Research hypotheses regarding the first question are:

- H1a: [Moderation] Serving size scores will be different between designs.
- H1b: [Diversity] Food item recognition and categorization scores will be different between designs.
- H1c: [Proportionality] Food groups and macronutrients percentages scores will be different between designs.
- H1d: [Hydration] Hydration scores will be different between designs.

The second question, meanwhile, asked participants' subjective perception on the design; if the design appears to be interesting, looking good, or suitable for proportionality visualization. Research hypotheses are:

- H2a: Design has a significant influence on Interestingness ratings.
- H2b: Design has a significant influence on Aesthetics ratings.
- H2c: Design has a significant influence on Proportionality Visualization ratings.

4. 2. Research Method

Design evaluation data were collected with an online survey questionnaire until 200 valid datasets were obtained (Power = 0.8, α = 0.05, effect size = 0.05). Male consumers in 30s were recruited as study participants, because the obesity rate (46.7%, KOSIS, 2019) and the overeating rate, i.e., eating more than 125% of recommended daily calorie intake, are the highest (13.8%, KCDC, 2018, pp. 202-203) in this age-gender group. Preventive measures targeted to this group, meanwhile, are expected to be the most effective; they have various motivations to stay in a good shape.

Part I of the online questionnaire tested H1a, H1b, H1c, and H1d. Participants were randomly assigned to either Q_Wheel group or Q_Lunchbox group where the corresponding FBDG was given. Participants studied the information in each FBDG and finished four groups of tasks exemplified in Appendix B.

(1) Moderation tasks:

(1.a) Serving sizes of given food items in weight. The Q_Wheel group saw a squid, potatoes, a watermelon piece illustrated in the Wheel design, while the Q_Lunchbox group saw a chicken drumstick, potatoes, and a watermelon piece included to the Lunchbox design.

(1.b) Serving sizes in Grains, Meat, and Fruits groups and where participants located relevant information in the FBDG.

(2) Diversity tasks:

(2.a) Identification of bean sprouts, corns, and lettuce in illustrations and photos.

(2.b) Categorization of mushroom, orange juice, walnuts, and coffee mix into five food groups.

(3) Proportionality tasks and where participants located relevant information in the FBDG

(3.a) Recommended food groups proportionality in percentage. The Q_Wheel group reported proportionality calculated with calories, while the Q_Lunchbox group reported proportionality calculated with weight.

(3.b) Recommended macronutrients proportionality in percentage.

(4) Hydration task: recommended fluid intake in cups.

In Part II of the online questionnaire, H2a, H2b, and H2c were tested with participants' ratings and comments on both Wheel and Lunchbox designs. Ratings on 10-point scales were given for Interestingness, Aesthetics, and Proportionality Visualization.

5. Data Analysis

5. 1. Communication Performance Scores

The Part 1 communication performance scores data were tested for normality and the results were all significant at $p < 0.01$. Non-parametric Mann-Whitney Wilcoxon U test was performed using the R software. The analyses of scores were summarized between designs (Table 2) and between tasks (Table 3).

Overall, Q_Lunchbox group scores (Mdn = 19) were higher than the Q_Wheel group scores (Mdn = 5) at $p < 0.001$. Moderation task scores were higher in Q_Lunchbox (Mdn = 5) than in Q_Wheel (Mdn = 1) at $p < 0.001$; H1a is accepted. Higher scores from the Q_Lunchbox group were foreseeable, considering relevant information was completely missing in the Wheel design. Diversity task scores were higher in Q_Lunchbox (Mdn = 6) than in Q_Wheel (Mdn = 3) at $p < 0.001$; H1b is accepted. The low recognition rates of bean sprouts (17%) and lettuce (48%) illustrations and low categorization scores of walnuts (10%) and coffee mix (28%) were much improved with the Lunchbox design. Proportionality tasks scores were higher in Q_Lunchbox (Mdn = 8) than in Q_Wheel (Mdn = 1) at $p < 0.001$; H1c is accepted. The Q_Wheel group responses to the Proportionality tasks showed clear discrepancies between expert recommendations and the popular beliefs of low-carb, high protein diet; participants thought that a third of their calorie intake should come from protein. Hydration task scores were higher in Q_Lunchbox (Mdn = 1) than in Q_Wheel (Mdn = 0) at $p < 0.001$; H1d is accepted.

Table 2 Communication performance comparison between designs

	Q_Wheel (n=100)			Q_Lunchbox (n=100)			Mann–Whitney U	
Task	Mdn	Q1	Q3	Mdn	Q1	Q3	W	p
Total sum	5.00	4.00	6.00	19.00	15.00	21.00	520.5	p < 0.001
1. Moderation	1.00	0.00	2.00	5.00	4.00	6.00	919	p < 0.001
1.a. Serving sizes in weight	0.00	0.00	0.00	3.00	3.00	3.00	827.5	p < 0.001
1.b. Serving sizes in Grains, Meat and Fruits	1.00	0.00	1.00	2.00	2.00	3.00	1915.5	p < 0.001
2. Diversity	3.00	2.00	4.00	6.00	4.00	7.00	1105	p < 0.001
2.a. Identification	1.00	1.00	2.00	3.00	3.00	3.00	552	p < 0.001
2.b. Categorization	1.00	1.00	2.00	3.00	1.75	4.00	2789	p < 0.001
3. Proportionality	1.00	0.00	1.00	8.00	5.00	8.00	1050	p < 0.001
3.a. Five food groups	0.00	0.00	0.00	5.00	3.00	5.00	960	p < 0.001
3.b. Three macronutrients	1.00	0.00	1.00	3.00	2.00	3.00	1325.5	p < 0.001
4. Hydration	0.00	0.00	1.00	1.00	1.00	1.00	2200	p < 0.001

Table 3 Communication performance comparison between tasks

Task			Q_Wheel (%)	Q_Lunchbox (%)
1. Moderation	1.a. Serving sizes in weight	squid/drumstick	3.00	85.00
		potato	0.00	82.00
		watermelon	12.00	84.00
	1.b. Serving sizes in food groups	Grains	40.00	73.00
		Meat	41.00	80.00
		Fruits	8.00	58.00
2. Diversity	2.a. Identification	bean sprouts	17.00	98.00
		corns	68.00	100.00
		lettuce	48.00	90.00
	2.b. Categorization	walnuts	10.00	52.00
		mushroom	87.00	85.00
		orange juice	36.00	70.00
		coffee mix	28.00	54.00
3. Proportionality	3.a. Five food groups	Grains	0.00	82.00
		Meat	2.00	77.00
		Vegetables	1.00	77.00
		Fruits	0.00	75.00
		Dairy	7.00	74.00
	3.b. Three macronutrients	carbohydrates	4.00	81.00
		protein	5.00	79.00
		fat	51.00	76.00
4. Hydration			30.00	85.00

5. 2. Design Properties Ratings Analysis

Subsets of ratings data were tested for normality and the results were all significant at $p < 0.001$. Mann-Whitney U tests were conducted for comparison (Table 4). Interestingness data analysis confirmed that Wheel (Mdn = 6.00) was considered more interesting than Lunchbox (Mdn = 5.00) at $p = 0.002$. H2a is accepted. The Q_Lunchbox group rated Wheel (Mdn = 6.00) significantly higher than Lunchbox (Mdn = 5.00) at $p = 0.007$. Aesthetics ratings data analysis also confirmed that Wheel (Mdn = 6.00) was considered more beautiful than Lunchbox (Mdn = 5.00) at $p = 0.002$. H2b is accepted. The Q_Lunchbox group also rated Wheel higher (Mdn = 6.00) than Lunchbox (Mdn = 5.00) at $p < 0.001$, while the Q_Wheel group ratings were not different between designs. Proportionality Visualization ratings, however, was not significant between the designs, so H2c is rejected.

Table 4 Design properties ratings comparison

	Group	Design	Mdn	Q1	Q3	W	p
Interestingness	QW	W	5.00	3.00	7.00	4640.50	0.09
		L	4.00	2.00	6.00		
	QL	W	6.00	5.00	7.00	6093.00	0.01
		L	5.00	3.75	7.00		
	QW_W + QL_W		6.00	4.00	7.00	21265	0.00
	QW_L + QL_L		5.00	3.00	6.00		
Aesthetics	QW	W	5.00	3.00	6.00	4289	0.49
		L	4.00	2.00	6.00		
	QL	W	6.00	5.00	7.00	6502	0.00
		L	5.00	3.00	6.00		
	QW_W + QL_W		6.00	4.00	7.00	21266	0.00
	QW_L + QL_L		5.00	3.00	6.00		
Proportionality Visualization	QW	W	5.00	2.00	7.00	3052	0.00
		L	6.00	4.00	8.00		
	QL	W	6.00	4.00	7.00	5498.5	0.22
		L	6.00	4.00	7.00		
	QW_W + QL_W		6.00	3.00	7.00	16705	0.21
	QW_L + QL_L		6.00	4.00	8.00		

Note. QW = Q_Wheel group. QL = Q_Lunchbox group. W = Wheel. L = Lunchbox.

5. 3. Qualitative data analysis

An analysis of participants' comments was summarized in Table 5. On Wheel, its design and ease of understanding were positively mentioned; *"interesting"*, *"original"*, *"organized"*, or *"easy to grasp at once."* The participants, however, also noticed that the Wheel did not provide critical information for practicing KDRIs guidelines, and the overall design was considered *"difficult to understand the message"*, *"too abstract"*, *"lacks specific information on serving sizes or calories"*, *"did not know that it is visualizing certain information"*, or *"could not read proportionality from the wheel."* Some reported the bicycle metaphor "being irrelevant to the content."

Lunchbox was reported to be more informative. Participants positively mentioned the serving size and proportionality information. The design was *"easy to grasp with useful information"*, *"intuitive"*, *"much better than the other design on serving size information"*, *"allows for easier comparison"*, and *"looking organized."* The same design, meanwhile, was reputed to be *"boring"*, *"not organized"*, *"not pretty"*, and *"difficult to understand"* due to its *"too much information."*

Table 5 Participants' comments and emergent codes

Food Balance Wheel				Food Balance Lunchbox			
Positive		Negative		Positive		Negative	
design	43	lack of information	49	information	42	design	61
easy to grasp	30	difficult to grasp	32	easy to grasp	25	difficult to grasp	32
information	9	design	25	design	16	lack of information	10
visibility	1	too much information	5	visualization	6	too much information	11
visualization	3	weak visibility	3				
		visualization	3				

6. Discussions: Improvements in the Food Balance Lunchbox

The communication performance analysis confirmed that the Food Balance Lunchbox functioned better as a FBDG than the Food Balance Wheel. Moderation scores and qualitative data confirmed that labelled photo icons effectively visualized serving sizes in weight and volume, and the participants appreciated it. Labelled photo icons also improved information granularity: what items are, how they are cooked, or what the quantity is. Food items with intricate details (steamed brown rice, bean sprout, e.g.) were effectively described as Talati et al. (2017) concluded. Photos, though, are limited in characterizing items without distinctive visual differences. Varieties of dairy products (whole milk, skim milk, or plain yogurt, e.g.) may look identical when they are photographed in glasses for serving size description. Labelled photo icons are strongly recommended, as some information is better clarified in text than implied in the image.

Displaying miscategorizable items, such as walnuts, in the Lunchbox design significantly improved Q_Lunchbox group categorization scores. Categorization of food into five food groups, though, may inaccurately render the consumer's idea of a food item's nutritional profile simpler than it really is. Lettuce, for example, is rich in fiber, but it also contains carbs, protein, and fat. Flour is a good source of carbs, but it also contains protein. For consumers with advanced food knowledge, an in-depth description of nutritional facts can be provided.

Proportionality scores confirmed that the Food Balance Wheel suggested inaccurate proportionality between food groups. On average, the Q_Wheel group read the rear wheel proportionality as Grains 28.33%, Meat 21.69%, Vegetables 18.84%, Fruits 12.28%, and Dairy 9.84%, which was significantly different from the recommended proportionality. 13% of the participants reported that they found no useful hints from the Wheel design. In contrast, the majority of Q_Lunchbox group recognized accurate percentage information. Proportionality Visualization ratings, however, were not statistically different between the two designs. Participants did not think the CCW treemap format assisted them to recognize proportionality better. The authors suspect that the visual complexity of the Lunchbox design—frequently mentioned as its weakness—prevented the participants from noticing the overall CCW treemap structure. Moreover, participants did not need to read slice proportionality, as percentages were already given in text.

For hydration information, the problematic water cup in the Food Balance Wheel was replaced with a more detailed text description of fluid intake in the Food Balance Lunchbox, and it significantly raised the Q_Lunchbox group Hydration scores. As extra calories from sugary drinks and fruits deserve attention, the Lunchbox design can be improved with further explanations on the difference between drinking plain water and other beverages, along with the personal differences in recommended fluid intake.

In summary, the Food Balance Lunchbox provided practical and actionable knowledge for healthy eating. The design was frequently considered as informative. Design properties ratings and qualitative data, however, showed that the design did not meet the participant's expectations on being interesting or appealing.

7. Conclusions

This study identified the communication problems in the current Korean FBDG, Food Balance Wheel, and proposed a new design of Food Balance Lunchbox in the CCW treemap format. A quantitative comparison of communication performance confirmed that the Food Balance Lunchbox successfully provided

personalized recommendations on serving sizes, food groups, proportionality between the groups, and fluid intake. With the Lunchbox design, healthy eating will be perceived as fathomable and doable. The analysis of qualitative comments, however, showed that the Food Balance Lunchbox needs aesthetic improvements to be well received by both children and adults.

An interactive version of the Food Balance Lunchbox is now under development as a solution to the current limitations, to allow for contextual presentation of information on user demands and avoid the cognitive burden of seeing all food icons at once. An interactive FBDG with a customizable food list and a proportionality visualization that compares the current calorie intake and recommendations will let consumers know where they need to reduce or increase; it will facilitate discussions on what constitutes healthy eating, through which various ideas will evolve and develop.

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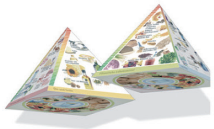
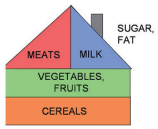
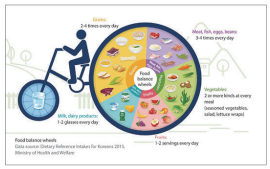
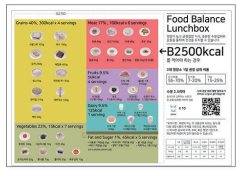
Title	Format	Moderation-Proportionality				Diversity		Hydration
		daily calories intake	serving size	servings	food groups proportionality	food groups	items	
The U.S. MyPyramid (Perelman, 2011)	pyramid 	none	none	√	√ area	• bread, cereal, rice, and pasta • vegetable • fruit • milk, yogurt and cheese • meat, poultry, fish, dry beans, eggs, and nuts • fats, oils, and sweets	illustration	none
The U.S. MyPlate (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015)	pie 	none	none	none	√ area	• fruits • grains • vegetables • protein • dairy	none	none
Germany 3D Food Guide Pyramid (Oberritter et al., 2013)	3d pyramid/ pie 	none	√	√	√ area	• cereals and potatoes • vegetables • fruits • milk and dairy products • meat, sausages, fish and eggs • fats and oils + water and beverages	photo	√
Japan Food Guide Spining Top (Japanese Ministry of Health, Labour and Welfare, 2010)	inverted pyramid 	none	√	√	√ area	• grain • vegetables • fish and meat • milk • fruits + water	illustration	√
The U.K. Eatwell Guide (Public Health England, 2018)	tilted pie 	√ gender difference	none	none	√ area	• fruit and vegetables • starchy food • dairy or dairy alternatives • protein: beans, fish, eggs, meat + unsaturated oils and spreads; food high in fat, salt and sugar	illustration	√

Title	Format	Moderation-Proportionality				Diversity		Hydration
		daily calories intake	serving size	servings	food groups proportionality	food groups	items	
Hungary House of Healthy Nutrition (Rodler, 2004)	house 	none	none	none	√ area	• cereals • vegetables and fruits • meats • dairy products • sugar and fat	none	none
Australian Guide to Healthy Eating (2013)	pie 	none	none	none	√ area	• grain • vegetables and legumes/beans • meats, poultry, fish, eggs, tofu, nuts, seeds, and legumes/beans • milk, yoghurt, cheese and/or alternatives, mostly reduced fat • fruit + foods high in fat, salt and sugar	photo	√
Finland The plate model (Fogelholm et al., 2014)	pie 	none	none	none	√ area	• vegetables • potato, rice, pasta or other cereal products • fish, meat, or egg • low fat dairy products or water • a slice of wholegrain bread with a thin layer of soft vegetable fat spread • berries or fruits	photo	√
Finland Food triangle (Fogelholm et al., 2014)	pyramid 	none	none	none	√ area	• random foods • red meat, processed meat, egg • fish, poultry • vegetable oils, margarine, nuts, seeds • low fat dairy products • whole grain staples and potato • bread, porridge, muesli • vegetables • berries and fruits	photo	none

	Food Balance Wheel	Food Balance Lunchbox
Task		

1. Moderation

1.a. Serving sizes in weight

According to the diagram above, how many grams are there in a serving of squid, potato, and watermelon?

According to the diagram above, how many grams are there in a serving of chicken, potato, and watermelon?

1.b. Serving sizes in the Grains, Meat, and Fruits groups

Mr. Kim's recommended daily calorie intake is 1200 kcal, while he is allowed to eat 50 kcal of fruits. Please choose the one right for him.

2. Diversity

2.a. Identification

What food do you see in the picture?

1. Oatmeal
2. Bean sprouts
3. Cereal
4. I don't know

What food do you see in the picture?

1. Oatmeal
2. Bean sprouts
3. Cereal
4. I don't know

2.b. Categorization

According to the above figure, which food groups do they belong to?

3.Proportionality

3.a. Five food groups

According to the figure above, if my recommended daily calorie intake is 2500 kcal, what percentages of it should I eat from the five food groups?

Grain ___%
Meat, fish, eggs, beans ___%
Vegetable ___%
Fruits ___%
Milk, Dairy production ___%
Oil, Sugar ___%
Total ___%

3.b. Three macronutrients

According to the figure above, if my recommended daily calorie intake is 2500 kcal, what percentages of it should I eat from carbs, protein, and fat?

Carbohydrate ___%
Protein ___%
Fat ___%
Total ___%

4. Hydration

According to the figure above, how many cups of water (a cup is 250 ml) do you need to drink per day, including water from food?