Doctoral Thesis

Using Gamified Nudges in Digital Food Environments to Influence Food Choice: Evidence from the United States and Vietnam

Bianca Curi Braga, MA
Doctoral candidate
Food and Nutrition Policy and Programs
Friedman School of Nutrition Science and Policy
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Thesis committee
Sean B. Cash, Ph.D. (Chair)
Bergstrom Foundation Professor of Global Nutrition
Friedman School of Nutrition Science and Policy

Aulo Gelli, Ph.D.
Senior Research Fellow
International Food Policy Research Institute

Norbert L. W. Wilson, Ph.D.
Professor of Food, Economics, and Community
Duke Divinity School
Affiliate professor
Friedman School of Nutrition Science and Policy

Abstract

Food environments have long been characterized as the economic, political, socio-cultural and physical dimensions that affect food choices and nutritional status. Digital dimensions, neglected in this definition, go beyond physical spaces and include social media, streaming services, phone applications, online grocery stores, and online marketing, among others. There is less comprehension of the impact of digital than physical food environments because the former are more novel, more rapidly evolving and more personalized. Studies on digital food environments are mostly about food labeling, food swaps, taxes and education interventions. Gamification, the use of game elements to motivate desired behavior outside of game settings, remains relatively unexplored as a tool to change the nutritional quality of food purchase and consumption. In this thesis, I tested:

Aim 1: The impact of gamification on the nutrient profile of foods purchased by American adults in The Grocery Store, a simulated online grocery store, in a randomized controlled pilot study (n=654) and a larger randomized controlled trial (n=1,112). The products in The Grocery Store displayed from one to five crowns, a visual scale based on the Guiding Stars nutrient profiling system. Foods added to the final shopping baskets had their number of crowns summed in a scoreboard. Participants received $30 or $50 to purchase 12 items from a shopping list. In the pilot study, gamification had an effect almost as great as increasing the shopping budget by $20. In the full experiment, gamification increased the total number of crowns, but budget was not statistically significant. There was improvement in the quality of food choices, especially for soups and sweet snacks, the list items with the least healthy choices among the control group.

Aim 2: The feasibility of the Food Recognition Assistance and Nudging Insights (FRANI) and its impact on the dietary quality of Vietnamese female adolescents through focus groups discussions (n=32) and a randomized pilot study (n=36). Adolescents liked using the application during the focus groups discussions, but suggested changes in the design, that were incorporated before the pilot study. FRANI's artificial intelligence recognized the foods consumed from the pictures taken by the adolescents and computed the amount of nutrient and food groups in the statistics page. Participants chose food consumption goals for food groups, for example eating dark green vegetables, and won points and badges for achieving them. There was high adherence to the app. The quality of food consumption was higher for the intervention group, that used the gamified version of FRANI, than for the control group, who had a FRANI version limited to food image recognition and dietary assessment. Participants in the intervention group had higher dietary quality measured by the number of food groups consumed from the Minimum Dietary Diversity for Women and Eat-Lancet Diet Score.

Gamification was highly effective to improve the quality of food purchase of adults in the United States and of food consumption of female adolescents in Vietnam. Governmental agencies should regulate digital food environments quickly and thoroughly paying special attention to the rise of gamification, since shopping for groceries online in high-income

countries and access to smartphones and internet in low- and middle-income countries are increasingly common.

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Chapter 1. Introduction: General statement of the problem, significance of the project and hypotheses

Rational Choice Theory, used in standard economics models, states that individuals effectively weigh costs and benefits given their constraints and preferences, and are affected by neither emotions nor external factors (Varian, 2006). According to this theory, individuals have unbounded rationality and unbounded willpower. Unbounded rationality is an unlimited information processing capacity, and unbounded willpower is making coherent decisions between short and long terms (Mullainathan & Thaler, 2000).

Behavioral economists use psychological concepts to include human limitations into the decision-making process (Battaglio et al., 2018; Mullainathan & Thaler, 2000). They argue that humans suffer from bounded rationality (Conlisk, 1996) and bounded willpower (Mullainathan & Thaler, 2000). Bounded rationality manifests as shortcuts in reasoning that constrain the ability to solve problems (Kahneman, 2011); bounded willpower leads to conflicts between present decisions and long-term interests (Battaglio et al., 2018; Mullainathan & Thaler, 2000). Humans also act out of habits, respond to social norms, and are influenced by peers and temporal constraints (O'Rourke & Lollo, 2015). Habits are routine actions done without cognitive effort, while social norms are examples of appropriate behaviors observed that influence decision-making (Kahneman, 2011). Temporal constraints are time limitations that pressure decision-making, possibly leading to suboptimal choices (Kahneman, 2011).

Nudge Theory proposes that the architecture of choice should acknowledge instincts and predictable irrationality to minimize systematic errors in decision-making generated by bounded rationality and willpower (Thaler & Sunstein, 2009). Nudges are simple, relevant, and often low-cost indirect suggestions and positive reinforcements that motivate people to make better decisions with minor effort (Thaler & Sunstein, 2009). Nudges require low cognitive or motivational effort, which is particularly useful for contexts in which individuals have little time to reflect on the 'best' decision (e.g., Münscher *et al.*, 2016). Examples of nudges are text messages promoting contact

avoidance during the COVID-19 pandemic (Sasaki et al., 2021); providing, translating, reminding and facilitating information on hand washing for healthcare professionals (Nagtegaal et al., 2019); modifying speed signs in roads to avoid car accidents (Rubaltelli et al., 2021); using label schemes to prevent the purchase of unhealthy foods (Shangguan et al., 2019); and strategically placing targeted products in food pantries (Wilson et al., 2017).

However, there is limited evidence on the effectiveness of nutrition interventions using gamified nudges to influence behavior. Gamification engages participants by using elements of games outside of an explicit game setting to change behavior (Deterding *et al.,* 2011), but is not designed to be played for entertainment alone. In gamification, rules on achieving goals and rewards are clearly stated, and rewards are given to participants that show desired behavior (Deterding *et al.,* 2011). Gamified interventions should incorporate intrinsic motivation – i.e., should align with the player's goals – otherwise, they run the risk of becoming unengaging, unsustainable over time, and ineffective (Högberg at al., 2019). Gamification is particularly effective when it meaningfully engages and challenges the player (Tobon, 2019). For example, Pokémon Go requires users to walk or bike to real-world locations to gain points by "hatching eggs," which increases physical activity (Winkler, 2019). Game elements have been used successfully in studies to improve parents and teens' nutrition literacy by teaching the importance of consuming fruits and vegetables and the potential harms of overeating sugar (Azevedo et al., 2019; Bomfim & Wallace, 2018). In another study, giving discounts for adults who answered quiz questions correctly on a mobile app influenced them to make healthier food choices (Högberg et al., 2019). Although the literature shows some success of gamified nutrition interventions, more research is needed about how game elements can influence food choice in online grocery shopping in high-income countries and with mobile phones in low- and middle-income countries. I aim to fill this literature gap by presenting results from both the Gamified Grocery Store (GGS) and the Nudging for Good (NFG) projects.

The GGS is based on a simulated online grocery store designed by a team based at Tufts University to test the impact of gamified nudges on the quality of food and beverage purchases in the United States (U.S.). We designed and populated this online grocery store

with recognizable foods and beverages typically sold in American grocery stores. Participants in the experiment performed a shopping task. The data generated were used to evaluate the impact of gamified nudges on the nutrition quality of their final shopping basket. The NFG is based on a mobile application, the Food Recognition Assistance and Nudging Insights (FRANI), designed by a team based at the International Food Policy Research Institute (IFPRI), Pennsylvania State University, the University of Ghana, the National Institute of Health of Vietnam and Thai Nguyen National Hospital in Vietnam to assess diets and provide gamified nudges to improve quality of foods and beverages consumed by users. The overall objective of this research is to investigate the impact of gamified nudges on the nutrient profile of foods purchased by American adults, as well as FRANI's feasibility and impact on the dietary quality of Vietnamese female adolescents.

Gamified Grocery Store

It was predicted before the COVID-19 pandemic that 70% of consumers would be shopping at least for some groceries online regularly between 2023 and 2025 (Food Marketing Institute, 2019). Although the consequences of COVID-19 for online commerce have not yet been fully realized, the number of people who bought groceries online increased by 43% (Yuen, 2022), and online grocery sales increased by 103% to $73.7 billion year-over-year in 2020 (Verdon, 2022). However, participants of the federal nutrition assistance programs such as the Supplemental Nutrition Assistance Program (SNAP) and the Women, Infants, and Children (WIC) were limited in most states to grocery shopping in physical stores where SNAP and WIC dollars were accepted (Leone et al., 2020). In 2020, Congress expanded the online purchasing program of SNAP for 45 states and the District of Columbia, impacting more than 90% of SNAP recipients (Aussenberg & Billings, 2020; USDA, 2021).

Although research on the impact of federal online nutrition assistance program expansions on dietary quality is limited, evidence suggests that online shopping helps consumers make more 'virtue' choices based on cognition and fewer 'vice' purchases based on visceral responses (Shiv & Fedorikhin, 2002; Milkman et al., 2010; Huyghe et al., 2017). The intensity of affective reactions to a product depends on the vividness of its presentation: more details facilitate mental representations (Loewenstein, 1996). The

more vivid a product, the more palpable and desirable, therefore the higher the instant gratification of its purchase (Loewenstein, 1996). Consumers who make online groceries see symbolic, pictorial representation of less vivid products than they would have seen in physical stores (Hoch & Loewenstein, 1991). This turns the anticipation of future gratification of consumption of products purchased online harder than products purchased in brick-and-mortar stores (Loewenstein, 1996).

Besides preventing consumers from impulse purchasing (Campo & Breugelmans, 2015; Huyghe, 2017), online grocery stores can provide access to healthy foods (Gorin et al., 2007) even in food deserts (Appelhans et al., 2013). However, consumers are hesitant to purchase fresh foods online (Clark & Wright, 2007; Martinez et al., 2018), which could lead to the purchase of less healthy and more processed foods (Pitts et al., 2018). Potential solutions to this problem are encouraging consumers to purchase canned, packaged frozen, and dried fruits and vegetables, and discourage impulse purchases (Milkman et al., 2010; Huyghe et al., 2017), and providing nutrition quality information such as labels (Epstein et al., 2016). The importance of online grocery shopping is expected to keep increasing; further research is needed to determine the most effective ways to engage consumers to make healthier choices using online grocery platforms (Jilcott Pitts et al., 2018). We aim at exploring gamified nudges as a potential new solution.

The Grocery Store is an experimental online grocery store with products from various brands and sizes commonly sold in American grocery stores that provides gamified nudges as a strategy to improve the nutrition quality of food choices of adults who live in the United States. The products in the store have Nutrition Facts Panels and ingredient lists following the Food and Drug Administration (FDA) guidelines, and scores from Guiding Stars, a nutrition profiling system (Guiding Stars, 2021). The Grocery Store displays gamified nudges: one (least nutritious) to five (most nutritious) crowns to illustrate to participants these scores for each product, and a scoreboard with the sum of the number of crowns of all products added to the shopping basket. If successful, this project could inform retailers, policymakers and regulators about new features to improve the quality of food choices in an increasingly important food environment.

My central hypothesis related to the GGS project is that gamified nudges significantly change the quality of foods and beverages purchased by American adults in the GGS. I test this hypothesis by pursuing the following specific aims:

Aim 1: Determine the impact of gamified nudges on the nutrient profile of foods purchased in the GGS.

Objective 1a: Determine the impact of gamified nudges on the nutrient profile of foods purchased in the GGS (relative to a control without gamified nudges).

H1a: The presence of gamified nudges changes the nutrient profile of foods purchased.

Objective 1b: Determine the moderating effect of a budget constraint on the relationship between gamified nudges and the nutrient profile of foods purchased in the GGS.

H1b: The budget constraint moderates the effect of gamified nudges on the nutrient profile of foods purchased.

Nudging For Good

There are 1.8 billion adolescents worldwide, of which 90% are in low- and middle-income countries (LMICs) (Gupta et al., 2014). The prevalence of underweight adolescents (individuals aged between 10 and 19) has not decreased much in the last three decades and the prevalence of underweight female adolescents is the highest in South Asia (Rodriguez-Martinez, 2020). Still, there has also been an increase in the prevalence of overweight (Jaacks *et al*., 2019). Changes in dietary intake and physical activity levels through modifications in the food systems and transportation modes and greater accessibility to activity-saving technologies have led to an increase in the prevalence of overweight and obesity (Popkin *et al.*, 2020). The prevalence of overweight girls has surged from <1% in 1975 to more than 5% in 2016 in LMICs (Rodriguez-Martinez, 2020). More than 25% of adolescents are overweight or obese in most Western Pacific countries (Saydah et al., 2013). Unhealthy weight in general during childhood and adolescence is associated with psychosocial problems, social stigmatization, poor self-image (Must, 1999), with non-communicable diseases in adulthood (Freedman et al.,

1999; Must & Strauss, 1999), and reduced life expectancy (Biro & Wien, 2010; Peeters et al., 2003; Virdis et al., 2009).

Although the double burden of malnutrition, or a high prevalence of both under- and over-nutrition in the same population, has been increasing faster in LMICs than in high-income countries (Popkin *et al.*, 2020), less is known about LMIC food environments (Hawkes et al., 2015; Kubik et al., 2003; Story et al., 2002). Moreover, few studies have investigated adolescents' dietary-related behaviors in low-income settings (Braga et al., 2021). However, there is evidence that interventions in the home, community, and workplace can shape the food environment and influence diets (Story et al., 2002; Claasen et al., 2016; Vepsalainen et al., 2015).

Technology-based interventions such as apps, text messages, internet-based curricula, and others have been used to teach adolescents about nutrition and healthy eating (Kaakinen *et al.,* 2018). Interventions delivered via the internet, gadgets, and telehealth (eHealth technology) are potentially engaging and scalable (Australia Bureau of Statistics, 2011). Personalized interventions can change behavior and help in clinical decision-making (Kumar *et al.*, 2013). Wearable sensors that collect real-time behavior and physiological data may improve data collection reach and quality, thereby increasing the opportunities for interactive and adaptive interventions (Turner *et al.*, 2015). Although screen time has been linked to sedentary behavior and obesity, mobile technology can be used as part of strategies to reduce risky behaviors that typically emerges in adolescence, including unhealthy diets (Champion *et al.,* 2019; Stiglic & Vinner, 2019).

FRANI tracks food choices, provides nutritional advice and positive feedback in the form of gamified nudges as a strategy to improve the diets and nutrition of adolescents living in urban settings in Vietnam. FRANI AI functionality is based on the classification of images of foods into food groups from pictures uploaded by users. The advices are tailored to each user, based on their food intake and food preferences, allowing them to make informed decisions to improve their diet. By addressing knowledge-related barriers to healthy food choices using information tailored to existing circumstances (e.g., location, time of day) and by enhancing self-awareness and motivation, adolescents will be equipped to improve decisions and behaviors related to

food consumption and diet, with potential positive spillovers into the behavior of their peers. If successful, this project could provide tools to monitor and influence the quality of individual food choice, with huge global relevance, and amass a wealth of real-time dietary quality data.

My central hypothesis related to the FRANI project is that gamified nudges improve the dietary quality of foods and beverages consumed by Vietnamese female adolescents. I plan to test this hypothesis by pursuing the following specific aims:

Aim 2: Evaluate the feasibility of FRANI and its impact on the dietary quality of female adolescents through focus groups discussions and a randomized controlled pilot.

Objective 2a: Qualitatively assess the acceptability and usability of the FRANI prototype among female adolescents from Vietnam through focus groups discussions (FGD).

Objective 2b: Quantitatively assess the feasibility of FRANI by measuring adherence, acceptability, and usability among female adolescents from Vietnam through a randomized pilot study.

H2b: FRANI is a feasible technology.

Objective 2c: Determine the impact of FRANI's gamified nudges on the dietary quality of adolescent girls from Vietnam through a randomized controlled study.

H2c: The dietary quality will be different in the presence of gamified nudges.

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Chapter 2: Literature review

Gamified Grocery Store

I undertook a literature review to assess the impact of online-based grocery store interventions aimed at improving the nutritional quality of food purchases of adults worldwide. I searched for articles in PubMed and Google Scholar without year limits using terms related to grocery stores, food and non-alcoholic beverages. The articles were included if 1) individuals in the sample were aged 18 years or older, 2) interventions were done in online grocery stores (simulated or real), 3) studies were published in English, 4) studies were available electronically, 5) studies had treatment and control groups, and 6) studies were peer-reviewed. I also included articles that analyzed the feasibility and acceptability of the features and functions of online grocery environments. There were no restrictions by intervention type.

Characteristics of the studies

Six independent randomized controlled trials (RCTs) studies and one systematic review met the inclusion criteria. Their characteristics are summarized in Table 1. The systematic review summarized the literature published until 2017, so all independent RCT studies included here were published after that. Considering the independent studies and the studies of the systematic review (Hartmann-Boyce et al., 2018), one was conducted in Australia, two in France (Egnell ey al., 2021; Ducrot et al., 2016), four in the Netherlands (Jansen et al., 2021; Nederkoorn et al., 2011; Waterlander et al., 2012; Waterlander et al., 2013 Waterlander et al., 2014), two in Singapore (Ang et al., 2019; Finkelstein et al., 2019), two in the United Kingdom (Forwood et al., 2015; Koutoukidis et al., 2019) and two in the United States (Coffino et al., 2021; Epstein et al., 2015). Most studies did not report the length of the intervention and did not have follow-up periods. Eleven studies were done through simulated stores and two were done in real online grocery stores.

The interventions followed four categories: economic (changes in price or financial rewards); swaps (replace food chosen by healthier alternative); labeling or education (informs consumers); other (any changes in the food environment not covered in the economic, swaps, and labeling or education) (Hartmann-Boyce et al., 2018). The intervention in four studies used only economic incentives to change behavior, while four

studies used only labelling and education (Ang et al., 2019; Ducrot et al., 2016; Egnell et al., 2021; Finkelstein et al., 2019), and two used only swaps (Forwood et al., 2015; Huang et al., 2006). One study used a combination of swap and labelling and education (Coffino et al., 2021), one used a combination of swap and other (default order of products) (Koutoukidis et al., 2019) and one used a combination of swap, labeling and education and other (norm message) (Jansen et al., 2021). All studies reported how they calculated the sample size.

Outcomes

The primary outcomes of the studies included changes in the purchase of foods and beverages, nutrients, energy, and dietary scores. The majority of the studies used data automatically collected during the experiment and self-reported demographic characteristics. The effects of the interventions are summarized by category. In Epstein et al., both subsidies (12.5% or 25% for healthy items) and taxes (12.5% or 25% for unhealthy items) lead to an increase in purchases of healthier items, but did not change total energy purchase. In Nederkoorn et al., a 50% tax on high-energy foods led to a significant decrease in the total energy purchase. In Waterlander et al., a 19% tax on sugar sweetened beverages led to a significant decrease in their purchase. Another study by Waterlander et al. compared a 25% discount on fruit and vegetables with no discount; the discount led to significant increase in the purchase of fruit and vegetables, without change in purchase in other food categories.

Huang et al. suggested swaps in a real online supermarket and observed a statistically significant decrease in saturated fat purchased. Forwood et al. did not detect any significant changes in the purchase of the energy density of foods for swaps in a simulated online grocery store. In Coffino et al., participants in the prefilled online grocery cart arm were successfully nudged by swaps compared with the nutrition education-only arm. Jansen et al. saw a significant impact of the Nutri-Score labeling and swap offer separately. Nutri-score was developed by the government of France to make comparisons across food products easier for consumers (De Temmerman et al., 2021). The effect of norm massage was not significant. Koutoukidis et al. found that swaps and changes in the default order of products in ascending order of saturated fat reduced saturated fat purchase. The change in default order reduced the percentage energy from

saturated fat more than the swaps. The combination of swaps and default order reduced saturated fat as much as the default alone, but more than the swap alone and the control group (Koutoukidis et al., 2019).

Ducrot et al. found that 5-color nutrition label, green tick, and multiple traffic lights labeling led to statistically significant benefits for at least one of the outcomes of the study. The label based on guideline daily amounts did not change purchase. No study included analyzed other types of interventions in online grocery shopping, and no study had statistically significant results for primary outcomes that were in the opposite direction of what was intended. Ang et al. found that front-of package warning labels can reduce demand for products high in sugar. However, the total sugar purchase (in grams and calories) did not change. Egnell et al. found that participants purchased less pre-packaged products in the Nutri-Score label group compared to no label. The Nutri-Score label led to a higher decrease in the purchase of the most unhealthy products (Egnell et al., 2021). In Finkelstein et al., the Alternative Healthy Eating Index – 2010 increased in the Nutri-Score and the Multiple Traffic Lighting groups compared to the control group. The Nutri-Score decreased the total saturated fats compared to control when only food items (excluding beverages) were analyzed (Finkelstein et al., 2019). The Multiple Traffic Lighting decreased the calories and fats per serving compared to the control (Finkelstein et al., 2019).

Convenience and time saving are the main motivations for shopping for groceries online (Jilcott Pitts et al., 2018). The possibility of multitasking while shopping, having to take care of family members, moving to a new home and social distancing during the Covid-19 pandemic are also reasons are some of the reasons why many individuals started doing their groceries online (Jilcott Pitts et al., 2018; Ellison et al., 2020). However, waiting for deliveries, delivery fees, and inappropriate substitutions are considered barriers for shopping for food and beverages online (Jilcott Pitts et al., 2018). Individuals also prefer buying fresh and perishable items in brick-and-mortar stores (Elms et al., 2016). Finally, consumers are less price-sensitive and make less comparisons online than in store (Chu et al., 2010).

Adherence

Most studies included reported the CONSORT flow diagram, from which adherence was calculated as the number of participants in the study divided by the number of eligible participants who were invited to participate in the study. No study had follow-ups. Only one study accessed feasibility and acceptability of the online grocery store used in the experiment, but answers were qualitative.

Author, year, country, type of store	Number of items in the store	Category of intervention	Study design, sample size and age	Length of the intervention and follow-up	Outcomes	Principal findings
Ang et al. (2019). Singapore. Simulated.	1800 non-fresh food and beverage products commonly purchased at local markets in Singapore	Labeling and education	Three armed RCT (n=512). Age mean 38.1 (SD=4.9).	Length not reported. No follow-up	Primary: Proportion of products purchased that were high in sugar. Secondaries: Total sugar purchased (in g) per shopping trip, sugar purchased per dollar spent (in grams per $), total spending (in $) given that high-in-sugar products tend to be less expensive, and total expenditure on high-in-sugar products ($)	The proportion of high-in-sugar products (%) significantly decreased by 0.06 (0.03) and 0.11 (0.03) with the stop sign and the warning labels, respectively. Total sugar purchase (g) did not change. Even an effective label that reduces demand for products high in sugar may not generate a reduction of total sugar or calories purchased.
Coffino et al., (2021). United States. Real.	Not reported	Swap, and labeling and education	Two-armed RCT (n=38). Age mean 47.5 (SD 14.2).	One month	Primary: Healthy Eating Index−2015 scores, energy (kilocalorie), and energy density (kilocalorie/gram) of each online cart (ie, grocery purchases) across 5-time points (week 0 −4)	Participants in the prefilled online grocery shopping cart arm were successfully nudged in a healthier direction, compared with individuals receiving nutrition education-only arm
Egnell et al., (2021). France. Simulated.	751 different foods and beverages, with raw and unpacked fresh products (N = 56 foods) and pre-packed foods (N = 695 foods)	Labeling and education	Three three-armed RTCs (n=1866; n=336; n=1180). Age mean 20.4 (SD 1.9); 41.3 (SD 5.9); 65 (SD 7.1)	Length not reported. No follow-up	Shopping cart composition in terms of number by types of foods (pre-packaged versus unpacked) and the degree of processing.	Participants purchase less food products, especially pre-packed, in the Nutri-Score arm than in the reference intakes (RIs) and no label arms. Indeed, − 4.27 pre-packed products on average were purchased in the Nutri-Score group compared to no label, and − 5.82 compared to the RIs. In particular, the Nutri-Score application led to higher decrease of less healthy foods classified from 'C' to 'E'. No significant difference was observed between the RI and no label.

Table 1: Summary of the randomized-controlled studies about interventions in online grocery stores to improve food choice

Author, year, country, type of store	Number of items in the store	Category of intervention	Study design, sample size and age	Length of the intervention and follow-up	Outcomes	Principal findings
Finkelstein et al., (2019). Singapore. Simulated.	More than 4,000 products commonly sold in the supermarkets of Singapore	Labeling and education	Cross-over trial where participants were allocated to 1 of the 6 intervention sequences (n=147). Age mean 34.6 (SD 6.8)	Length not reported.	Primary: Modified version of the Alternative Healthy Eating Index (AHEI) - 2010. Secondary: The weight (by serving) average Nutri-Score of the shopping basket, and the total and per serving values of sugar (g), energy (kcal), fat (g), saturated fat (g), sodium (mg), fiber (g) and protein (g).	The increase in the AHEI was 1.09 in Nutri-Score (NS) ($p = 0.04$) and 1.16 in Multiple Traffic Lighting (MTL) ($p = 0.04$) compared to control. There was an increase in NS by 0.33 points ($p < 0.01$) compared to control and by 0.31 points ($p < 0.01$) compared to the MTL. For food items only, there was a significant effect of the NS on average NS (0.21, $p = 0.02$) and total saturated fats (–29.79g, $p = 0.01$) relative to control. There was a significant decrease of calories per serving by 20.56kcal/serving ($p = 0.02$) and fats per serving by 1.02g/serving ($p = 0.03$) from MTL relative to control. No other differences were statistically significant.
Hartmann-Boyce et al., (2018). France (1), United States (1), United Knigdom (1), Australia (1), Netherlands (3). Real (1), simulated (6).		Economic (4), swap (2) and labeling or education (1)	Searched 13 electronic databases on June of 2017 using terms related to grocery stores, food choice and purchase and nutrition; (n=13,913)	Multiple lengths and follow-up periods (studies published until June of 2017)	Overall nutritional quality, total energy (kcal) of subsidized foodstotal basket energy density (kJ/100g), saturated fat (% from energy), total fruits and vegetables (number of items), sugar sweetened beverages (liter)	Economic interventions had the highest proportion of statistically significant results. No study had statistically significant results for primary outcomes that were in the opposite direction of what was intended

Table 1: Summary of the randomized-controlled studies about interventions in online grocery stores to improve food choice (continuation)

Table 1: Summary of the randomized-controlled studies about interventions in online grocery stores to improve food choice (continuation)

Author, year, country, type of store	Number of items in the store	Category of intervention	Study design, sample size and age	Length of the intervention and follow-up	Outcomes	Principal findings
Jansen et al., (2021). Netherlands. Simulated.	Not reported	Swap, and labeling and education, and other (norm message)	RCT with eight conditions in a 2 (swap offer: yes versus no) × 2 (Nutri-Score: yes versus no) × 2 (norm: yes versus no) between subject design. Age mean 45.1 (SD=16.5)	Length not reported	Combined nutrient profile (NP) score of the chosen products of each of the four conditions each participant was exposed to	NP score was significantly impacted by Nutri-Score (NS) labeling ($F(1,542) = 6.93$, $p < .01$) and swap offer ($F(1,542)= 58.74$, $p < .001$), while the effect of norm message was not significant ($F(1,542) = 1.24$, $p = .27$). There was no statistically significant 2-way and 3-way interaction. NS label and a swap decreased the combined NP score with 3.3($p <.001$) and 9.6 ($p <.001$) (The lower the score, the healthier).
Koutoukidis et al., (2019). United Kingdom. Simulated.	About 11,000 products from a real UK grocery retailer	Swaps and other (default order of products)	Four-armed RCT (n=1088). Age mean 38 (SD=12)	21 minutes (SD=9). No follow-up	Primary: The difference in the saturated fat content of the basket measured as the difference in the percentage of total energy between adjusted for total energy each of the four trial groups. Secondary: The proportion of products with less than 1.5 g of SFA per 100 g of product (1.5% SFA); the cost of the basket, expressed as £/100 g; the total energy (kcal), energy density (kcal/100 g), sugar (percentage of total energy), and salt (g/100 g).	Compared with the control, changing the default order of products to show foods in ascending order of saturated fat (SFA) (n = 261) reduced SFA by − 5.0% (95% (CI: − 6.3 to − 3.6)), and swap with lower SFA (n = 279) reduced it by 2% (95% (CI: − 3.3 to − 0.6)). Changing the default order reduced the %energy from SFA significantly more than offering swaps (− 3.0% (95% CI: − 4.3 to − 1.6). The combined intervention (swap + default order) (n = 273) was significantly more effective than control (− 5.4% (95%CI: − 6.7 to − 4.1)) and swaps alone (− 3.4% (95%CI: − 4.8 to − 2.1)), but there was no difference from changing the default order alone (− 0.4% (95%CI: − 1.8 to 0.9), p = 0.04 for interaction).

Nudging for Good

A review of the literature on digital-based interventions aimed at improving the dietary quality of adolescents worldwide was undertaken to assess: 1) tools that could be used to nudge them to make healthy food choices; 2) the effectiveness of interventions and how success wasmeasured for these types of interventions, and 3) how diet-related apps can be made attractive to users. We searched for articles in PubMed and Google Scholar without year limits. We included articles if 1) individuals in the sample were adolescents (aged 10 to 25 years), 2) interventions used electronic devices or computers to improve nutrition outcomes, 3) studies were published in English, 4) studies were available electronically, 5) studies had treatment and control groups, and 6) studies were peer-reviewed. We also included articles that analyzed the feasibility and acceptability of the technology used to change food-related behaviors. No article analyzed usability (or features and functions of technology). We excluded articles about electronic interventions that had as the only goal to improve behavior related to dietary-related psychological problems such as anorexia and bulimia nervosa.

Characteristics of the studies

Seven independent randomized controlled trials (RCTs) studies and two systematic reviews met the inclusion criteria. Their characteristics are summarized in Table 2 and Table 3. The systematic reviews summarized the literature published until 2014, therefore we only included all independent RCT studies that were not included in these two reviews. We use the word "independent" for RCT studies that were not part of these systematic reviews. Of the independent RCT studies, two were conducted in the United States (Chen *et al.,* 2018; Jake-Schoffman *et al.,* 2018), two in Canada (Chamberland *et al.,* 2017; Goodman *et al.,* 2018), one in the Netherlands (Alblas *et al.,* 2018), one in Hong Kong (Abraham *et al.,* 2015), and one in Thailand (Rerksuppaphol & Rerksuppaphol, 2017). Of the 24 studies included in the two systematic reviews considered (Champion *et al.,* 2019; Ho *et al.,* 2018), 18 were conducted in the US, two in Belgium, one in Mexico and Spain, one in Malaysia, one in the Netherlands, and one in Portugal.

Considering all independent RCT studies and the ones that were part of the systematic reviews, the types of technology-based interventions included internet-based

curriculum to improve nutrition knowledge, cell phone calls and texts, computer games, apps, emails, accelerometers, and pedometers. Besides technology, studies used in-person visits to clinics, in- school participation, mindfulness techniques, and parental participation (Abraham *et al.* 2015; Chamberlant *et al.,* 2017). Two of the seven independent RCTs and ten studies from the 24 evaluated in the systematic reviews had parental participation (Abraham *et al.* 2015; Champion *etal.,* 2019; Ho *et al.,* 2018; Jake-Schoffman *et al.,* 2018). Intervention periods varied from one ten-minute session to 12 months (Alblas *et al.,* 2017; Ho *et al.,* 2018). The follow-up period was alsoextremely heterogeneous, ranging from two weeks to 36 months (Champion *et al.,* 2019).

Outcomes

The primary outcomes of the studies included anthropometric indicators such as body mass index (BMI) and BMI z-score, waist and hip circumference, and dietary intake such as consumption of sugar-sweetened beverages, fats, fried foods, fast-foods, fruits and vegetables, milk and alternatives, vitamin D, as well as biomarkers of micronutrient status including the blood concentration of vitamin D. Other outcomes were physical activity, TV and computer screen time,and feasibility and acceptability of the technology used in the interventions, and implicit attitudes towards food and dietary intake (Abraham *et al.,* 2015; Jake-Schoffman *et al.,* 2018). The majority of studies used self-reported data to measure the impact of interventions on anthropometry, physical activity, dietary intake, and knowledge in nutrition and health (Abraham *et al.,* 2015; Alblas *et al*., 2017; Chamberlant *et al*., 2017, Champion *et al*., 2019, Chen *et al*., 2018, Goodman *et al*., 2018, Ho *et al*., 2018, Jake-Schoffman *et al.,* 2018). Outcomes measured by health professionals included BMI and blood concentrations of vitamin D (Chamberlant *et al.,* 2017; Goodman *et al.,* 2018; Rerksuppaphol & Rerksuppaphol, 2017). In one of the studies, weight, height, waist and hip circumference, and blood pressure was measured but it was not clear whether these outcomes were self-reported (Abraham *et al.,* 2015).

Dietary intake was self-reported in all studies (Abraham *et al.* 2015, Chamberlant *et al.,* 2017, Champion et al., 2019; Chen et al., 2018, Goodman et al., 2018, Ho et al., 2018, Jake- Schoffman *et al.,* 2018). Two of four independent RCT studies that analyzed the impact of interventions on the consumption of fruits and vegetables showed an increase in consumption during the intervention (Alblas *et al.,* 2017; Chamberland *et al.,*

2017; Chen *et al.,* 2018; Jake- Schoffman *et al.* 2018). In a school-based experiment, students in the intervention group consumedmuch higher fruits and vegetables compared to the control group (6.4 vs. 3.7 servings/day) (Chamberland *et al.,* 2017). In contrast, another study which parents and children dyads used a mobile app, accelerometers and pedometers did not find treatment effects for fruits and vegetable consumption, but found increase in fruit consumption (0.3 servings/day) in both groups over time (Jake-Schoffman *et al.,* 2018). The two studies that tried to change implicit attitudes towards the consumption of fruits and vegetables, via internet-based school curriculum (Chamberland *et al.,* 2017) and computer game interventions (Alblas *et al.,* 2017), were not successful. One study did not report results on dietary intake (Abraham *et al.,* 2015). Data from the nine studies included in one of the systematic reviews showed a small but significant increase in the mean servings per day of fruits and vegetables in the immediate post-intervention period, without significant heterogeneity between trials (Champion *et al.,* 2019). These effects were not sustained in the follow-ups, but there was heterogeneity on the number of mean servings per day of fruits and vegetables between the follow-up trials (Champion *et al.,* 2019).

The consumption of milk and milk alternatives, and intake of vitamin D was found to have increased post-intervention in two RCTs (Chamberland *et al.,* 2017; Goodman *et al.,* 2016). A school curriculum-based intervention stimulated an increase in the consumption of milk and milk alternatives (Chamberland *et al.,* 2017). Post-intervention, students in the intervention group consumed more milk and milk alternatives than the ones in the control group (3.5 vs 1.6servings/day) (Chamberland *et al.,* 2017). In other study, participants in the intervention group received emails reminding them to complete records of vitamin D consumption through an app, and to watch videos, and read education slides with key points related to vitamin D and health (Goodman *et al.,* 2016). Mean vitamin D intake increased significantly from pre- to post-test (407IU vs. M=619 IU) and more in the intervention than in the control group (F=4.09) (Goodman et al., 2016). Mean blood vitamin D3 increased significantly from pre- to post-test (M=28 vs. M=43nmol/L) but did not differ significantly between intervention and control groups (Goodman *et al.,* 2016). Knowledge related to the importance of the consumption of Vitamin D increased significantly only in the intervention group (Goodman *et al.,* 2016).

Out of all the independent RCT studies, only two involved interventions to decrease the consumption of sugar-sweetened beverages (Chen et al., 2018; Jake-Schoffman et al., 2018). Adolescents had a statistically significant reduction in sugar-sweetened drink consumption (z=- 0.44, p=0.001) (Chen et al., 2018). Also, children had not had a significant decrease in daily serving consumption of sugar-sweetened beverages (− 0.1 servings, p = 0.05) (Jake-Schoffman etal., 2018). Four studies from the systematic reviews assessed the intake of sugar-sweetened beverages and high-energy snacks, but generally no change was seen immediately after the intervention, nor at follow-up (Champion et al., 2019). No difference was found in breakfast nor fast-food consumption between treatment groups (Chen et al., 2018).

Two out of three independent RCT that were not sufficiently powered to detect treatment effects of internet-based curriculum and knowledge interventions on BMI reported a decrease in this outcome (Chen et al., 2018; Rerksuppaphol & Rerksuppaphol, 2017). Another study designedan intervention in which adolescents in the intervention group had internet training about physical activity and nutrition, mindful training sessions and visited an obesity clinic, but had no impact on BMI, body fat or on blood pressure (Abraham et al., 2017). Another study did not find significantly different body weight change between the intervention and control groups (1.3 ± 1.9 vs. 1.1 ± 1.9 kg), p=0.37 (Chamberland et al., 2017). A null result was also observed for changes in BMI z-scores between intervention and control groups (−0.09 ± 0.02 vs. −0.04 ± 0.03 kg, respectively; p=0.12) (Chamberland et al., 2017).

In an experiment in the US, adolescents in the intervention group had a statistically significant reduction in BMI (z=-4.89, p<0.001) and BMI z-score (z=-4.72, p<0.001) compared to adolescents in the control group (Chen et al., 2018). In Thailand, children and adolescents had significantly higher BMI, BMI z-score, weight z-score and waist-to-height ratio in the control group than in the intervention group (Rerksuppaphol & Rerksuppaphol, 2017). There was also a significantly higher percentage of overweight or obese individuals in the control group than in theintervention group (56.6% vs. 39.6%) (p=0.009) (Rerksuppaphol & Rerksuppaphol, 2017). Moreover, compared to baseline, children in the intervention group had no changes in weight z- score (-0.04, 95%, CI -0.16 to 0.07, p=0.438) and BMI z-score (-0.001, 95%, CI -0.19 to 0.18,

p=0.988) at the end of the study (Rerksuppaphol & Rerksuppaphol, 2017). However, children in the control group had significant increases in weight z-score (0.25, 95%, CI 0.11 to 0.39, p- value<0.001) and BMI z-score (0.45, 95%, CI 0.27 to 0.63, p-value<0.001) at the end of the study (Rerksuppaphol & Rerksuppaphol, 2017). Both systematic reviews concluded that technology-based interventions that aimed at reducing BMI had small to null impact (Champion et al., 2019; Ho et al., 2018).

None of the three independent RCT studies that aimed at changing physical activity levels detected improvement in physical activity, although none of these studies were sufficiently powered to do so (Abraham et al., 2015; Chen et al., 2018; Jake-Schoffman et al., 2018). Two of them used pedometers and accelerometers to collect data (Chen et al., 2018; Jake-Schoffman et al., 2018). From the systematic reviews, one of the studies included used pedometers and three used accelerometers to measure physical activity (Champion et al., 2019; Ho et al., 2018). The intervention that used the pedometers relied on self-reported data collected by this device, though no effect was detected on physical activity (Patrick et al., 2013). All other interventions studies included in the systematic reviews relied on self-reported data based on questionnaires (Champion et al., 2019; Ho et al., 2018).

Two interventions aimed at lowering blood pressure (Abraham et al., 2015; Chen et al., 2018). One did not observe an impact of the internet curriculum, cell phone calls and reminders in blood pressure (Abraham et al., 2015), while the other did not report results on this outcome (Chenet al., 2018). Implicit attitudes concerning food were also generally found not to change post- intervention (Alblas et al., 2017). The two independent RCT studies that analyzed the feasibility and acceptability of interventions based on internet-based curriculum, cell app, email, as well as phone calls/texts, accelerometer, and pedometer, were successful in improving diet and health outcomes (Abraham et al. 2015; Jake-Schoffman et al. 2018). Feasibility and acceptability outcomes were measured according to the usage of intervention material (i.e., logins in intervention platform) and self-reported data collection (Abraham et al. 2015, Jake-Schoffman et al., 2018).

Adherence

Out of the seven RCTs included, three gave precise, quantitative information on

adherence rates, of which two reported high adherence (Abraham et al. 2015; Goodman et al., 2016; Jake-Schoffman et al. 2018). The systematic reviews did not report relevant information on adherence.Abraham and colleagues reported a high response rate, but there was no impact in diet and physical activity, possibly for lack of power (Abraham et al. 2015). Also, Jake-Schoffman and colleagues showed overall high retention rates, feasibility, acceptability, and an increase in self-monitoring steps, consumption of fruits, and a decrease in the consumption of sugar-sweetened beverage (SSB) (Jake-Schoffman et al. 2018). However, the study was underpowered as well (Jake-Schoffman etal., 2018). Goodman and colleagues showed low adherence to the intervention protocol and no difference in blood concentration of vitamin D between control and treatment groups (Goodman et al., 2016). Still, there was an increase in self-reported vitamin D intake that may be explained by differential drop-out rates in the control and intervention groups (Goodman et al., 2018).

Author, year, country	Study design, sample size and age	Length of the intervention, follow-up and description of intervention	Type of technology-based intervention	Food-choice related outcomes	Other outcomes	Principal findings: effect of the intervention	Adherence
Abraham et al. (2015). Hong-Kong.	RCT n=48. Mean age= 14.4 y Age range=12 to 18 y	T1) Care visit at an obesity clinic + 12 week internet training, modified internet curriculum that consisted of twelve 15-minute interactive sessions with information about nutrition and physical activity. Relaxation mindful eating practices. Cell phone follow-up over 6 months. T2) Personalized dietary and exercise advice at each visit to the clinic conducted by dietitian/nutritionist. Parental participation. This was a 6-month intervention. C) Usual care visit at an obesity clinic.	Internet-based curriculum with cell phone calls/texts reminders	Primary: feasibility of adapting and using an existing internet curriculum and nutritional program with cell phone follow-up for obese teens. Secondary: dietary intake, and knowledge related to nutrition	Primary: none. Secondary: physical activity level, stress level, and knowledge related to physical activity, weight and blood pressure.	The high recruitment rate, high retention rate, high internet log-in rate, and reasonable compliance with completion of online curriculum sessions and use of cell phone reminders show that the curriculum is feasible. Patients also reported good satisfaction with the curriculum. No impact of the interventions on the BP, body fat, BMI, physical activity and stress. The impact on dietary intake was NR.	T1) 14 out of 16 subjects read the curriculum (87.5%). The majority of subjects (71%) completed all lessons. Only four parents read the curriculum. T2) A total of 400 messages were sent to 16 subjects. 15 subjects opted to receive the message by cell phone and one preferred email only. The response rate to dietary goals and exercise goals were 78.3% and 77.5%, respectively.
Alblas et al. (2017). The Netherlands.	RCT (2X2X2 mixed subject design) n=125 Mean age=20.17 y with SD=1.88. Age range 18 y	T) Play 10 minutes of computer game which goal is to supply a fictitious island with as much healthy foods as possible to avoid sinking. C) Similar to treatment but used clean and fossil fuel instead of foods. Experiment took 2 months.	Mobile app, accelerometers, pedometer, email with program materials and newsletter.	Primary: Implicit attitudes towards foods at baseline and after the health game or the control game. Foods used in the experiment were fruits and chocolate snacks.	None	Participants playing the control game had significant reduction ($p<0.001$) in healthy IAs from baseline (M=0.86, SE=0.05) to post-test (M=0.69, SE=0.05), while for participants playing the health game, the reduction from baseline (M=0.85, SE=0.05) to post-test (M=0.79, SE = 0.05) healthy IAs was significant ($p=0.021$).Health games reduced healthy implicit attitudes in control groups, but did not change implicit attitudes in treatment group. Baseline implicit attitudes did not moderate the effect of health game. Those with healthy implicit attitudes in baseline were more affected by the health game in virtual choice than those with less healthy implicit attitudes in baseline.	Not reported

Table 2: Summary of the randomized-controlled studies about interventions with technology to improve food choice in adolescence

RCT stands for randomized controlled trial; T) stands for treatment group (T1 is treatment group one, T2 is treatment group 2); C) stands for control group.
NR stands for not reported .Y stands for years-old; *Blood pressure was mentioned was one of the variables measured in the study, but results were not reported

Author, year, country	Study design, sample size andage	Length of the intervention, follow-up and description of intervention	Type of technology-based intervention	Food-choice related outcomes	Other outcomes	Principal findings: effect of the intervention	Adherence
Chamberlandet al. (2017). Canada.	Clustered RCT (Randomizationof school classes) n=282. Mean age=13.6 y. Age range =13 to 14.	Classes were randomized to intervention (modified curriculum) and control (regular) for 6 weeks. Participants in the intervention were instructed to enter their consumption of fruits and vegetables 2x/day from 5x/week. Follow-ups in the 2nd, 4th and6th weeks (intervention period), in which 2-week summary reports were analyzed by students with the help of teachers. Also follow-ups in the 9th and 17th (after intervention period).	Internet-based nutrition interventio n	Primary: Consumption offruits and vegetables, milkand alternatives	BMI z-scoresand body weight change	Students in the intervention group consumed an average of 6.4 daily servings of fruits and vegetables and 3.5 daily servings of milk and alternatives, while the control group consumed an average of 3.7 servings of fruits and vegetables and 1.6 servings per day after at the intervention. These differences were statistically significant. Body weight change was not significantly different between the intervention and control groups (1.3 ± 1.9 kg vs 1.1 ± 1.9 kg, P = 0.37, respectively). The same was observed for changes in BMI z-scores (intervention: −0.09 ± 0.02 kg; control: −0.04 ± 0.03 kg, P = 0.12).	Attendance at school for entering data on the website influenced the success of the program. It was harder to complete data entry when students missed classes. Many students struggled to take responsibility outside ofschool hours to record their data.
Chen et al. (2018). USA.	RCT pilot. n=40. Mean age=14.9 with SD=1.67.	Usage of wearable sensor for 6 months, participation on 8 online education modules for three months(intervention length), and after completing the modules received tailored, biweekly text messages for three months. All assessments wereconducted at baseline, three monthsand six months.	Wearable sensor (Fit-bit Flex), online education and text messages	Primary: None. Secondary: Sugar-sweetened beverage, breakfast, fast- food, fruits and vegetables, diet, self-efficacy	Primary: BMI and BMI z-scores. Secondary: screen time, physical activity, self-efficacy, physical health and psychosocialhealth	Adolescents in the intervention group had statistically significant reduction in BMI (z=- 4.89, p<0.001) and BMI z-score (z=-4.72, p<0.001), sugar-sweetened drink consumption (z=-0.44, p=0.001), screen time (z=-0.51, p<0.001), and increased self-efficacy in nutrition(z=0.11, p=0.02) and physical activity (z=0.16, p=0.5). No difference was found in breakfast, fast-food consumption, vegetable and fruit consumption and physical activity time between intervention and control groups.	Not reported
Goodman etal. (2016). Canada	RCT. n=90. Intervention n=59 and control n=50. Mean age=22 with SD=2. Agerange=18 to 25.	Intervention length was 12 weeks (36 recording days). On weeks 3, 6 and 9,intervention participants received an email that reminded them to completetheir recordings, as well as a vitamin D newsletter. The mean study duration was 128 days with SD=31 days.	Vitamin D-calculator app, goal setting check-in email, and videos and education slides with 8 key points related to vitamin D.	Primary: Intake, knowledge, and/or perceptions of vitamin D amongthis sample of young adults. Blood concentrations of25(OH)D3.	None	Mean vitamin D intake increased significantly from pre-test (M=407, SD=460 IU) to post-test(M=619, SD=655 IU), p<0.001. Mean intake increased more in the intervention than in the control group (F=4.09, p=0.046). Mean blood vitamin D3 increased significantly from pre-test(M=28, SD=16 nmol/L) to post-test (M=43, SD = 29 nmol/L), p<0.001, but did not differ significantly between groups. Vitamin D knowledge increased significantly only in theintervention group.	Over a third of participants submitted no app recordings.Among those who participated, the average rateof app submissions was 58%(M = 21 recordings).

Table 2: Summary of the randomized-controlled studies about interventions with technology to improve food choice in adolescence (continuation)

Author, year, country	Study design, sample size and age	Length of the intervention, follow-up and description of intervention	Type of technology-based intervention	Food-choice related outcomes	Other outcomes	Principal findings: Effect of the intervention	Adherence
Jake-Schoffman et al. (2018). USA.	RCT. Randomization of dyads (parents and adolescent). n=33. Intervention group 1 n=16. Intervention group 2 n=17. Mean age parents=43 with SD=5.8. Mean age adolescents=11 with SD=0.9. Age range=9 to 12 y.	Intervention length was of 12 weeks. At baseline and follow-up, dyads wore accelerometers for seven days. In the twelfth week, both intervention groups received study materials and correspondence.	Mobile app, accelerometer, pedometer, email with program materials and newsletter.	Primary: feasibility, acceptability and preliminary effectiveness of two family-based health promotion programs that had food choice related-goals (fruits and vegetables, sugar-sweetened beverage and fast-food)	Primary: Feasibility, acceptability and preliminary effectiveness of two family-based health promotion programs that also had non-food-choice related goals (physical activity)	The intervention was feasible and accepted. There were no group by time differences for physical activity or healthy eating. However, there was a significant increase in average daily steps (1397 steps, p = 0.04) and servings of fruit (0.3 servings, p = 0.02) and a marginally significant decrease in children's daily servings of sugar-sweetened beverages (− 0.1 servings, p = 0.05) when intervention groups of parents and children were combined.	The overall retention was of 94%. Parents: Kept step and food logs for an average of 9.4 weeks (SD=3.7) (median=12). Read an average of 8.5 weekly newsletters (SD=3) of the 12. Adolescents: kept step and food logs for an average of 9 weeks (SD=3.9) (median=11.5). Read an average of 5.2 weekly newsletters (SD=4.3) of the 12. Families: downloaded an average of 5.7 apps (SD=3.1) of the 12 apps sent with the weekly newsletter. 89% of families downloaded week 1 app, but rates declined throughout the weeks.
Rerksuppaphol & Rerksuppaphol (2017). Thailand.	RCT. n=218. Control n=106. Intervention n=111. Age mean=10.7 with SD=3.	Intervention length was of 4 months. Anthropometric data were collected at baseline and every following month.	Internet-based program to collect data on nutrition, anthropometry and physical activity.	None	Primary: Changes in percentage of overweight and/or obese children at the end of the study. Secondary: Changes in BMI, waist and hip circumference.	Children and adolescents in the control group had significantly higher BMI, BMI z-score,weight z-score and waist-to-height ratio than children and adolescents in the intervention group. There was a significantly higher percentage of being overweight or obese in the control group (56.6%) than in the intervention group (39.6%) (p=0.009). Compared to their baseline, children in the intervention group had no changes in weightz-score (-0.04, 95%CI -0.16 to 0.07, p=0.438) and BMI z-score (-0.001, 95%CI -0.19 to 0.18, p=0.988) at the end of the study. Children in the control group had significant increases in weight z-score (0.25, 95%CI 0.11 to 0.39, p-value<0.001) and BMI z-score (0.45, 95%CI 0.27 to 0.63, p-value<0.001) at the end of the study, but children in the intervention group had not.	Not reported

Table 2: Summary of the randomized-controlled studies about interventions with technology to improve food choice in adolescence (continuation)

Author, year	Country	Study design, sample size and age	Length of the intervention and follow-up	Type of technology-based intervention	Outcomes	Principal findings effects of theintervention	Adherence
Champion et al. (2019)	Systematic review with studies from the USA (n=10), the Netherlands (n=1), Belgium (n=2), and Mexico and Spain (n=1)*	14 publications. Sample sizes ranged from n=91 to n=4158. Total sample n=18,873 students. Mean age: 13·41 years (SD 1·52). Age range:11-18 years.	The duration of the interventions ranged from one 20-30-minute session to three years. 21 trials had follow-up sessions that ranged from 2 weeks to 36 months.	Internet, computers, tablets, mobile technology, or tele-health	Consumption of SSB, fats, fruits And vegetables, physical activity, screen time, smoking and alcohol consumption	Electronic-health school-based interventions significantly increased fruit and vegetable intake, but no effects were seen for fat or sugar-sweetened beverage or snack consumption. Interventions significantly increased accelerometer-measured and self-reported physical activity, and reduced screen time immediately after the intervention. However, effects were not sustained at follow-up when data were available.	Not reported
Ho et al. (2018)	Systematic review with studies from the USA (n = 8), Portugal (n =1), and Malaysia (n =1).	10 publications. Sample sizes ranged from n=57 to n=101 participants. Total sample size n=505. Mean age ranged: 13.1-15.2 years. Age range: 11-18 years.	The duration of the interventions ranged from 3 months to 12 months. Three trials had follow-up sessions, that ranged from 8 months to 24 months.	Internet-based interventions that used self-guided programme through a web-site with interactive components.	Primary: BMI and BMI z-score. Secondary: quality-of-life, psychosocial, physical activity and frequency of fried food consumption.	Internet-based self-monitoring interventions exerted a small effect size on the reduction of BMI.	It was unclear if intervention impacts were sustainable in the long term as only three trials presented follow-up data and one trial reporting follow-up beyond one year.

Table 3: Summary of the review studies about interventions with technology to improve food choice in adolescence

*We did not include the studies from Champion et al. which interventions were to exclusively reduce smoking and alcohol consumption.

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Chapter 3: The creation of an online grocery store for experimental purposes: A pilot study

[Under review at *Food Quality and Preference*]

Bianca C. Braga[1], Sean B. Cash[1], Katrina Sarson[1], Remco Chang[2], Ab Mosca[3], and Norbert L. W. Wilson[4]*

[1]Curi.Bianca@tufts.edu; Sean.Cash@tufts.edu and Katrina.Sarson@tufts.edu; Friedman School of Nutrition Science and Policy, Tufts University, Jaharis 150 Harrison Avenue, Boston, MA 02111

[2]Remco@cs.tufts.edu; Computer Science, Halligan Hall, Tufts University, 161 College Avenue, Medford, MA 02155

[3] A.Mosca@northeastern.edu; Khoury College of Computer Sciences, Northeastern University, 440 Huntington Avenue, 202 West Village H, Boston, MA 02115

[4] Norbert.Wilson@duke.edu; Divinity School and Sanford School of Public Policy, 304 Gray, 407 Chapel Drive, Duke Box, #90968, Durham, NC 27708-0968

*Corresponding Author

Abstract

More households shop for groceries online than ever in the United States. Thus, changes in online grocery store environments can affect the nutritional quality of food choices on a large scale. In response, we built a simulated online grocery store for experimental purposes. This paper describes the development of an online grocery store that displays actual products, brands, sizes, prices, pictures, and ingredient lists sold in current online grocery stores in the United States. We ran a pilot study to evaluate this research tool by calculating adherence and accounting for participants' experiences. We assessed the impact of game elements (point scoring and a scoreboard) and different budgets on the nutritional quality of the food bundle in the final shopping baskets of participants (n=654). Participants in the treatment group saw the nutritional quality rating system illustrated for each food item as 1 to 5 "crowns." Ordinary least square regressions compared the nutritional quality of the final shopping baskets between experimental groups. Participants who saw the game elements selected food bundles with 2.53 (CI 95% [0.72;4.33], p=0.006) more crowns in their final basket. Receiving a high budget ($50) increased the number of crowns by 2.78 (CI 95% [0.66;4.90], p=0.010) compared to a low budget ($30). We found no significant interaction between the game intervention and budget level. Participants noted that the store was intuitive to navigate, had a high-quality interface, and easily found the products they often buy. The game elements encouraged shoppers to make healthier food choices. Our simulated grocery store can help researchers gain insight into online consumer behavior by testing interventions.

Keywords: food choice, nutrition quality, online food environment, grocery shopping, gamification, behavior

1. Introduction

Online grocery shopping surged during the height of the COVID-19 pandemic (Ellison et al. 2021, Redman 2021). Concomitantly, the United States Department of Agriculture (USDA) expanded the use of the Supplemental Nutrition Assistance Program (SNAP, formally the Food Stamp Program) in online grocery stores. However, mixed early evidence of the healthfulness and cost-effectiveness of food selected online suggests that online purchases may differ from in-store food purchases (Chester et al., 2020, McCarthy, 2021, Olzenak et al., 2020, Headrerick et al., 2022, Huyghe et al. 2017, Coffino, et al. 2021). In addition, federal policy in the US does not require the display of Nutrition Facts Panels for products in online grocery stores, potentially complicating healthful food choices online (Pomeranz et al., 2021).

Extensive research has explored the effect of intervention in simulated and actual in-store and online grocery stores (van Herpen et al., 2016; Hartmann-Boyce et al., 2018). However, given the importance and potential growth of online grocery shopping, researchers need accessible tools for evaluation. Simulated online grocery stores can potentially be practical and valid instruments to study food choices if they recreate the most salient aspects of real-life online grocery stores. Some researchers have used online grocery platforms to evaluate sustainable food choices (Demarque et al. 2015; Kanay et al. 2021; Panzone et al. 2021a; and Panzone et al. 2021b), while others have assessed the impact of nutrition information on the nutritional quality of food purchases (Waterlander et al., 2011; Waterlander et al., 2015). For example, nutrition advice lowered the saturated fat of products in shopping baskets in Australia (Huang et al., 2006). Labels helped to change the nutrient profile score of foods sold in the Netherlands (Jansen et al., 2021) and improved nutrition indicators (Finkelstein et al., 2019) in Singapore but not in the US (Howe et al., 2022). Labels also reduced the demand for products high in sugar in Singapore (Ang et al., 2019) and decreased the purchase of pre-packaged foods, especially for the most unhealthy products in France (Egnell et al., 2021). Offering product swap suggestions in an online grocery store did not lower the energy density of selected foods (Forwood et al., 2015); however, product placement lowered the saturated

fats of food selection in the United Kingdom (Koutoukidis et al., 2019) and the US (Howe et al., 2022).

Despite the potential advantages of simulated online environments for research, studies so far have little detail about the construction of the stores (Hartmann-Boyce et al., 2018). Furthermore, descriptions miss product inclusion and exclusion criteria (Hoenink et al., 2020; Forwood et al., 2015), and simulated stores often exclude popular food and beverage brands (Waterlander et al., 2011). We constructed The Grocery Store to enable externally valid experimental tasks based on products representative of typical grocery stores in the United States. This article describes product selection and participants' experiences in The Grocery Store, which are important steps toward transparency of the digital food environments literature.

Further, we ran a pilot study, assessed adherence to experimental tasks, and asked participants open-ended questions about their experiences. Participants shopped for groceries constrained by a budget to assess the response to the nutrition value of selected foods in an environment where all products had the Nutrition Facts Panel. Economic analysis of consumer demand assumes optimization of a utility function that incorporates individual preferences and takes income and prices as given. The result of this optimization is a set of individual product demands expressed as functions of the budget parameters (McFadden & Fosgerau, 2012). Moreover, the quality of food consumption is lower for households with lower incomes in the US and energy-dense foods cost less both in real-life grocery stores and in our store (Drewnowski, 2010; Waterlander et al., 2010, Zhang et al., 2018). In addition, the field of behavioral economics expands the basic economic framework to acknowledge that context and choice architecture can shape consumer choices (Caputo and Just, 2022). In this pilot study, we explore the effect of introducing game elements to the shopping experience on the nutrition quality of food choice.

Interventions should not exclusively focus on information and education (Kirschenbaum & Gierut, 2013), as knowledge alone is often insufficient to modify and maintain healthy behavior (e.g., healthy food choices) (Schaefer & Magnuson, 2014; Webb & Sheeran, 2006). Part of the sample was randomized into "gamified" conditions that included point scoring and visualization of progress to encourage healthy food

choices latently. Gamification is the use of game elements such as points scoring, leaderboards, and progress indicators as incentives to engage and motivate behavior outside of game settings (Deterding et al., 2011; Forde et al., 2016, Hamari et al., 2014, Mekler et at., 2017, Seaborn and Fels, 2015). Recent articles suggested that granting points through audio clues from devices like Amazon Alexa and Google Assistant motivated housecleaning behavior (Bauer and Mazarakis, 2022). Researchers in the gamification literature have used points, badges, and leaderboards based on Social Determination Theory, which suggested that game elements spured intrinsic motivations, thus altering behavior toward a predetermined goal (Ryan & Deci, 2000). Thus, a gamified environment does not necessarily produce "winners" competing against other participants, nor does it need to award real prizes.

Gamification can help participants process information more automatically, especially for implicitly delivered messages (Baranowski et al., 2016). It can also enhance exposure to a health intervention (Baranowski, Buday, Thompson, & Baranowski, 2008) because it attracts, captures, and maintains attention by being fun (Ritterfeld, Cody, & Vorderer, 2009). Gamification has become a popular tool to incentivize behavioral change (Parisod et al., 2014), for example, to train physical and mental behavior to lower body mass index (Lu, Kharrazi, Gharghabi, & Thompson, 2013; Van 't Riet, Alblas, Crutzen, & Lu, 2015), promote green energy consumption (Hamari et al., 2017), and help language learning (Vesselinov & Grego, 2012). We extend this literature by using game elements to inform the nutrition quality of foods in an online grocery store. We hypothesized that gamification and budget level change the final shopping baskets' nutritional quality.

2. Materials and Methods

Researchers from the Visual Analytics Lab at the Department of Computer Science and the Friedman School of Nutrition Science and Policy at Tufts University created The Grocery Store, a simulated online grocery store built to be easily adaptable to our experimental goals. The Grocery Store is analogous in product variety, design, brands, sizes, prices, pictures, Nutrition Facts Panels, and ingredient lists to mid-sized

grocery stores in the United States. This realistic environment serves multiple experimental purposes and facilitates the study of how food environments can affect food choices on a variety of topics, including nutrition quality, gamification, budget, sustainability, price, labeling, and others.

2.1 The Grocery Store data sources

The research team licensed Syndigo and Guiding Stars data to build the Grocery Store. Syndigo is a company that provides standardized images, Nutrition Facts Panel data, and product descriptions to online and brick-and-mortar grocery retailers (Syndigo, 2022). Guiding Stars uses algorithms informed by an independent science advisory panel to provide a rating system for fresh, packaged, and prepared foods. Participating retailers, for example, Ahold Delhaize in the US, display the nutrition rating in brick-and-mortar stores as "Guiding Stars" shelf tags and in online stores. Researchers have evaluated the ability of the Guiding Stars system to encourage healthy food choices (Guiding Stars, 2018; Fischer et al., 2011; Sutherland et al., 2010).

The Guiding Stars system is consistent with the Dietary Guidelines for Americans and the Food and Drug Administration (FDA) labeling policy (Guiding Stars, 2018). The Guiding Stars algorithm evaluates the nutrient content of foods using the Nutrition Facts Panel and the ingredient list on the packaging (Guiding Stars, 2018) unless they are below a caloric threshold (for example, water and spices). In addition, the algorithm standardizes products to 100 kilocalories serving sizes for evaluation and consumer comparison. It only evaluates nutrients in foods with significant scientific consensus concerning health promotion or disease prevention (Guiding Stars, 2018).

The Guiding Stars system credits foods with points according to the presence of vitamins, minerals, fiber, whole grains, omega-3 fatty acids, and monounsaturated fatty acids (for fats and oils only). It deducts points for the amounts of trans fatty acids, saturated fatty acids, added sodium, added sugars, artificial colors, and food dyes. The algorithm produces a net score for each product from -41 to +11. The Guiding Stars company deems foods with a positive score as healthy and foods with a zero or negative score as unhealthy.

The Guiding Stars uses a system of visual cues – "Guiding Stars" – to indicate the healthiness of food. Participating supermarkets display one (healthy) to three (healthiest) Guiding Stars for food and beverage products on brick-and-mortar aisles and online. However, for products deemed unhealthy, those products do not receive Guiding Stars. Additionally, Guiding Stars does not evaluate products below a calorie threshold; thus, products like spices and water do not receive Guiding Stars. Therefore, we excluded these products and most beverages, except milk, from the Grocery Store. The 2022 revision of the Guiding Stars system rated water.

We used the Guiding Stars point system but converted the visual cues from Guiding Stars to crowns and created a scale from one (lower Guiding Stars score) to five (higher Guiding Stars score) crowns. As a result, every food in The Grocery Store had a Guiding Star score and the associated crowns. This greater granularity of one to five crowns, instead of one to three Guiding Stars, allowed for more differentiation between products, namely unhealthy foods, and gave research participants more information about every product. As a result, unhealthy foods, which comprised 89% of the products displayed in The Grocery Store, received one or two crowns instead of no Guiding Stars. The breakdown of the number of points and Guiding Stars is in Table 1.

<<Table 1>>

2.2 Product Selection for the Grocery Store

Previous research has used different simulated grocery store environments. For example, Koutoukidis et al. (2019) and Forwood et al. (2015) used a supermarket simulation in the United Kingdom with more than 11,000 items, whereas Machin et al. (2017) offered 232 products. For The Grocery Store simulation, we worked with Guiding Stars to identify the most purchased items within food categories representative of the sales at typical American mid-sized grocery stores. In addition, Guiding Stars provided information about product sales movement by category and appropriate aisle placement for the selected food items.

The movement sales of units or pounds purchased in partner supermarkets dictated the inclusion of products from the Guiding Stars database in The Grocery Store. We excluded products that were not food (for example, flowers) or not relevant for our

experimental purposes (for example, spices, fats and oils, and infant and toddler foods). Most exclusions were due to the lack of enough sales movement suggesting a lack of relevance to the typical American consumer. The Grocery Store extracted 7,000 universal product codes (UPC) and Global Trade Item Numbers (GTIN) from the Guiding Stars database, of which about 4,800 scored zero or fewer Guiding Stars points. We matched the UPCs and GTINs extracted from Guiding Stars with UPCs and GTINs from Syndigo. The data from Syndigo included product information (pictures, ingredient lists, and nutrition information) (Syndigo, 2022).

The Grocery Store excluded the 1,638 items from Guiding Stars without corresponding information from Syndigo. Product prices from the Guiding Stars database varied by item, company, market region, and period. The Grocery Store prices are the average retail prices over two weeks: The first week was October 12 to 18, 2019, which reflected the data extraction period from the Guiding Stars database. The second week was May 16 to 22, 2020, which reflected prices impacted by Covid-19 and excluded summer seasonality. We used an average retail price across markets for one week when the average retail price was unavailable for both weeks.

2.3 The Grocery Store Display

The Grocery Store contains 5,362 UPCs and GTINs commonly sold in American grocery stores from various national and local brands and sizes. The Grocery Store displays products by movement (most to least sold) and is organized into ten categories: Bakery, Breakfast, Canned Goods, Dairy & Eggs, Dry Goods & Pasta, International, Frozen, Pantry, Produce, and Snacks. In addition, the categories represent 54 smaller sub-categories, such as Bread, Canned Soup, and Fresh Fruits. The detailed list of subcategories by category of food in the Store and the number of items of each is in Appendix 1. From the nutrient information, the research team developed Nutrition Facts Panels following the FDA guidelines for packaged foods with data from Syndigo (2021). All participants could see the Nutrition Facts Panels and ingredient lists by clicking on the items.

3. Pilot Study

We ran a pilot study to test adherence to experimental tasks (defined as shopping for 12 food items from a list), the impact of gamification (point scoring and a scoreboard) and different budgets on the nutritional quality of the food bundle in the final shopping baskets of participants. In addition, after participants completed the shopping task, we surveyed them about the store navigation and the ease of finding products they typically purchase when doing their real grocery shopping.

We recruited participants (n=654) in Amazon Mechanical Turk. At the end of the experiment, twenty-one participants, randomly selected from the study sample, answered open-ended questions about their shopping experience in The Grocery Store. The inclusion criteria for participation were being physically in the United States, aged 18 to 65 years, comfortable reading English, and having an Amazon Mechanical Turk approval rate of 90% or more. The team received IRB approval from Tufts University under protocol #00001170. The experiment randomly assigned participants to one of four experimental conditions: Presence or absence of gamification (hereafter called the "game") and high ($50) or low ($30) budgets (a 2 x 2 full factorial design). We set the budget values according to a pre-pilot test with 59 participants in which the mean expenditure was $30.49 (SE 3.97), the median expenditure was $31.23, and no one spent more than $48.51. The subjects in the condition with the game saw crowns and a scoreboard (Figure 1), while participants in the non-game version did not see the crowns or scoreboard (Figure 2).

No participant saw the underlying Guiding Stars scores, but all participants could see the Nutrition Facts Panel for all products (Figure 3). Those in the game conditions saw one to five crowns for every item in The Grocery Store. The instructions page defined and displayed the crowns as "one crown (least nutritious) to 5 crowns (most nutritious)", but they were not explicitly encouraged to choose products with more crowns. The Grocery Store instructed participants to browse the categories and sub-categories (corresponding to aisles) and select desired products. Participants received instructions to place selected products on the 12-item shopping list -- bread/bakery; rice/grains/pasta; beans; soups; sweet snacks; salty snacks; crunchy snacks; milk; cheese; vegetable/fruit; breakfast/cereal; and eggs.

Online shopping studies commonly use shopping lists to standardize shopping baskets and make them more readily comparable (Forwood et al., 2015; Koutoukidis et al., 2019). Following previous studies (Forwood et al., 2015; Koutoukidis et al., 2019), we provided a shopping list to support comparability across bought products, collectively and individually. The reason is that nutrition scientists are interested in dietary quality (the quality of foods consumed). However, the typical instruments used to measure dietary quality, such as 24-hour recalls, food frequency questionnaires, food diaries, and weigh food records, are not valid to measure the quality of food purchased. With the list, we do not know the impact of changes in food purchases on dietary quality, but we can observe a change in the quality of foods purchased for breakfast or a snack. If food purchased changes, the dietary quality potentially has changed, holding everything else constant. The absence of a shopping list would make comparing baskets difficult to understand the dietary quality change. Also, we based list items such as bread and cheese to increase observing socioeconomic purchase variability (Forwood et al., 2015).

The shopping list served as means to encourage the completion of the shopping exercise and was merely for guidance since participants were free to include foods from any category of The Grocery Store in any of the shopping list items. For example, they could include a cereal for the soup shopping list item or an apple as a crunchy snack. Finally, when consumers shop, they have different goals: some shop for a single meal, the week's food needs, or various needs. However, allowing a "free shop" would mean we would have a potential confounder: the motivation for the shopping trip. The shopping list mitigates unobservables such as intent, foods at home, or social desirability. This design helps to see how consumers shop when looking for similar classes of products.

As participants selected products, The Grocery Store discounted the price from the remaining budget (Figure 4). They could replace any item in the shopping cart until the check out. Finally, participants could check out having spent more than the initial budget because we wanted to avoid participants choosing cheaper products that they do not consume in real-life only to be able to checkout and complete the task. Also, we wanted to understand how or if the budget binds. For example, the $30 group should feel that their choices were constrained but still have the possibility of buying 12 items they

consume in real-life, while the $50 group should not feel constrained. After checking out, participants answered sociodemographic questions and a subsample (n=21) were randomly selected to answer open-ended questions about general navigation, navigation in the aisles, checkout, and finding the items they typically consume. Each person could only participate in the experiment once. We conducted data analyses with Stata 16.1/IC. Characteristics of the participants are in Table 2.

<<Table 2>>

4. Results

Of the initial sample (n=654), only 23 (3.5%) participants exceeded the assigned budget. Of these, 22 were in the $30 budget group. The full sample comprised mostly individuals aged 25 and 34 (n=299) and 35 to 44 (n=206). Most were men (n=421) and white/Caucasian (n=468). Most had an income between $35,000 and $74,999 (n=300), were college-educated or more (n=479), were primary grocery shoppers (n=601), and were online grocery shoppers (n=401). However, 48% answered that they often do not have money to buy enough food, 31% often had to cut the size of their meals, and 44% said they could not afford a healthy diet. The randomization algorithm sent one of every four participants to the control and the game and low-budget groups; the low-budget groups summed 156 participants.

4.1 Quantitative Results of the Pilot Study

The 12-item shopping list allows participants to collect between 12 and 60 crowns in their final basket. We conducted separate analysis with the whole sample recruited (n=654) and with those who adhere to the shopping task (n=503), defined as having a final shopping basket with exactly 12 products (Figure 5). We did not have a target sample size, but this pilot will help us calculate the sample size for a future, larger study. The analysis with the whole sample showed that participants in the no-game and low-budget group had an average of 28.30 (SE 3.23) crowns, while those who saw the game and low budget had 29.11 (SE 3.28) crowns (Figure 6). Those in the high-budget group that did not see the game had an average of 29.95 (SE 1.89) crowns, but participants in the game had an average of 33.02 (SE 2.11) crowns. The number of Guiding Stars points

was positive for those who saw the game elements (mean=2.49; SE=0.14) and negative (mean=-4.98; SE=0.27) for those who did not see the game elements, independent of budget. Ordinary least squares (OLS) regressions compared the number of crowns in the final shopping baskets between groups for the whole sample (Table 3a) and only for those who adhered to the experimental tasks (12 items in the final shopping basket; Table 3b).

<<Tables 3a and 3b>>

Participants in the game group chose products with an average of 2.53 crowns (CI 95% [0.72;4.33], p=0.006) more than the participants not in the game. In addition, the high budget relative to the low budget led participants to choose foods with more crowns in the final shopping basket: A $50 budget increased the number of crowns by 2.78 (CI 95% [0.66; 4.90], p=0.010) compared to having a $30 budget. Finally, we estimated a model of the game's interaction and budget. With the interaction term, all of the coefficients are insignificant. Participants who adhered to the shopping task (n=503) spent on average $25.93 (SE 1.27) in the low-budget group and $31.96 (SE 3.49) in the high-budget group. The odds ratio of adherence given the high budget was 1.514 (CI 95% [1.118; 1.910]). The game was relevant to explain the nutritional quality of the final shopping basket of those who adhered to the experimental tasks (p-value<0.000), but the high budget was not (p-value=0.921). However, in the model of the interaction of the game and the budget, the coefficients are statistically insignificant.

In the full sample (n=654), higher expenditures correlated with more crowns, but this correlation disappeared for the subsample of participants (n=503) that adhered to the instructions of selecting 12 items (Figure 7). Only 3.5% (n=16) of the total sample spent more than the initial budget, and only 1.0% (n=7) spent more than the initial budget after non-adherent participants were excluded. According to an exploratory analysis, the budget became significant for the regressions with interactions between game and budget after excluding those who spent more than the initial budget (Appendix 2). All variables but the interaction between game and budget were significant when the regressions had game, budget, expenditure (money spent during the game), the interactions of these variables and the number of products in the final shopping basket as explanatory

variables (n=654).[1] The effect of game, budget and expenditure was positive, but diminished the higher the expenditure (Appendix 3).

4.2 Open-ended Responses about the Experience in The Grocery Store

Five of the twenty-one participants who answered open-ended questions about their shopping experience in The Grocery Store mentioned minor website navigation problems. One stated that the pictures were small, and two said the images loaded slowly: "Just slow loading times for the product photos, otherwise good." Eighteen participants did not mention any issues with the navigation in the aisles (categories and subcategories) of food in The Grocery Store: "The aisles were very easy to navigate, and I found everything I needed quickly." Two participants suggested changes: adding a search bar and the experimental shopping list on the side. All participants said they did not have a problem with the checkout process: "The checkout process was seamless, easy to replace, and easy to see the items in the cart." Overall, the navigation seemed intuitive and easy to most: "I had no issues, the task was very understandable and intuitive."

5. Discussion

Building an online grocery store that mimics real online platforms presents challenges. Our goal was to create a simulated online grocery that represented nationally available products and avoid scrapping data from accessible websites. Our team initially tried to build The Grocery Store with data from the United States Department of Agriculture (USDA) Branded Food Products Database. However, this database did not present enough product diversity to match the contemporaneous grocery stores. Therefore, we purchased and merged data from Syndigo and Guiding Stars, and built Nutrition Facts Panels for all products in The Grocery Store according to the FDA's guidelines using data from Syndigo. The Guiding Stars Scientific Advisory Panel revised the algorithm according to the Food and Drug Administration modifications after we built the current version of The Grocery Store (Guiding Stars, 2018). The Grocery Store products and scores do not include the Daily Value and Nutrition Facts Panel revisions of 2020. We excluded nonfood products, foods Guiding Stars did not evaluate, and foods

[1] We thank an anonymous reviewer for suggesting this additional exploratory model specification.

with relatively low sales. As a result, we had 5,376 products and prices representing top-selling items in grocery stores.

The Grocery Store was a reasonable representation of real online grocery stores. Most participants who completed the open-ended questions about their experience in The Grocery Store described the navigation as intuitive and easily found the products they often purchase in real-life online grocery shopping. In addition, the pilot test results showed that most participants completed the grocery shopping task and that gamification improved the quality of final shopping baskets. This pilot study identified challenges with the experiment, for example, we learned of problems with slow loading issues of pictures, which may have hampered adherence to experimental rules. However, an important finding was that the participants in the higher budget had higher odds of adhering to the experimental rules. In addition, we observed that the randomization process generated few participants in the control group than anticipated. These discoveries were useful for restructuring The Grocery Store for future experiments.

Our experiment did not answer if the motivation for selecting foods with more crowns was intrinsic (achieve a high score) or extrinsic (eat healthier). Gamification may have worked as a game, influencing participants only to achieve higher score, or may have informed consumers about the quality of the shopping basket. Icons (or badges) that signal the quality of products and work as soft prizes increase self-efficacy (Sailer et al. 2017) and engagement (Hamari et al., 2017) in previous experiments. But so far, badges worked better when visible to third parties, as a social signal, for example, stimulating the reuse of hotel bath towels (Baca-Motes et al., 2013). Badge-like incentives that could not be socially exhibited did not motivate pro-social behavior (Van der Weele & Von Siemens, 2020), including for sustainable food choices in online grocery shopping (Panzone et al., n.d.). Even in the absence of social exhibition or competition, the crowns and the scoreboard together led to changes in the quality of the final shopping basket in our study.

Critics have questioned the moral legitimacy of gamification because it can harm players unintentionally, recklessly, negligently, or inadvertently (Bogost, 2015; Kim 2015; Sicart 2015; Selinger, et al. 2015). Scoreboards, leaderboards, and competition can be taken as a stick or a carrot depending on the context and design (Anderson & Pildes,

2000). For example, a leaderboard system displayed on video screens for the housekeeping staff at Disneyland hotels in California resulted in considerable anxiety, embarrassment, and shame among workers (Lopez, 2011). The system, which workers nicknamed "the electronic whip," ranked employees' performance against their colleagues on a large screen. Some workers reportedly avoided taking bathroom breaks, while others became worried about losing their jobs (Lopez, 2011).

Companies should develop ethical frameworks for gamification that consider safety, security, privacy, transparency and accountability to avoid potential misuses, such as taking unfair advantage of workers and consumers (Kim & Werbach, 2016). Governments should regulate gamified environments based on adequate rational after identifying the individuals subject to gamification, considering their level of vulnerability, and the motivations of the organizations implementing it. Validated nutrient profile models and indicators that maximize the dietary quality of the population should be used whenever a point systems influence purchases or consumption of food.

The high budget increased the nutritional quality of the final shopping basket as measured by crowns. Still, the effect disappeared when only those who adhered were analyzed (final shopping baskets with 12 items). This result and the insignificant interaction between budget and gamification may be explained by the small sample size in the low-budget conditions. Furthermore, 15.26% (n=76) of high-budget participants and 41.67% (n=65) of the low-budget participants did not adhere to the shopping task. Low-budget participants may have adhered less to the task because foods with more crowns are more expensive in some categories of The Grocery Store. A low budget as an additional shopping constraint may have also imposed a cognitive load, making participants quit the task (Mani et al., 2013). Finally, the low budget group was smaller than anticipated, and we adjusted that randominzation for future studies. Future experiments should investigate what increases the likelihood of low-budget participants complete the task, including testing the effect of learning with repeated shopping trips. Progress in games requires repetition, and repetition targets automatic processes (Bandura, 1986; Ciavarro, Dobson, & Goodman, 2008).

The crowns may have led to an experimental demand effect that increased the intention to buy healthy products independently of gamification (Zizzo et al., 2010).

Potentially, the presence of the crowns may have led to automatic information processing of the nutritional quality of the products. Automatic (i.e., impulsive) processes, involved in all aspects of food consumption, require little or no cognitive effort, while deliberate (i.e., reflective) processes are slow and demand high cognitive effort (van't Riet et al., 2011a,b). Thus, the crowns alone could shape the food choice of participants. Also, the shopping list may have activated self-control, altering the effect size of gamification (Davydenko & Peetz, 2020; Massara, Melara, & Liu, 2014; Sjåstad & Baumeister, 2018). Some studies have permitted participants to shop freely, without a shopping list (Coffino et al., 2021; Egnell et al., 2021; Epstein et al., 2015), but two-thirds of individuals shop with lists in real life (Basset et al., 2008; Thomas & Garland, 2004; Davydenko & Peetz, 2020).

This hypothetical exercise may have led to food choices potentially less representative of real-life shopping habits, while other experiments exchanged real-life money for physical products (Demarque et al., 2015; Muller, Lacroix, & Ruffieux, 2019; Kanay et al., 2021; Panzone et al., 2021a; Panzone et al., 2021b). Some of these studies had smaller sample sizes from a limited geographical area, in which participants had their food choices delivered. As we conducted this national experiment during the early days of the Covid-19 pandemic, lock-down orders restricted our efforts. Still, our large sample with people from various occupations, age ranges, levels of income, and geographical areas has advantages over more tightly controlled samples frequently of students or from a single city. Admittedly, our sample had a disproportionate representation of young men, white/Caucasian, and college-educated. Future studies need to address these limitations.

A growing body of evidence identifies the contribution of unhealthy food environments to unhealthy eating (Swinburn et al., 2013), and the importance of public policy and regulation to promote healthy food environments and prevent disease (Duran et al., 2021). Nutrition regulations have focused more on physical than digital food environments. Scientific work on the regulatory aspects of online grocery stores is almost non-existent, but the existing studies show that nutrition information is not consistently provided (Headrick *et al.*, 2022 and Pomernanz *et al.*, 2022). The literature has less information on the digital than physical food environments because digital environments are more novel and more rapidly evolving. Digital food environments are also harder to

evaluate because they are personalized, while many individuals share physical food environments. Even the definition of food environments, typically the economic, political, socio-cultural and physical dimensions that affect food choices and nutritional status, exclude digital settings (Swinburn et al., 2013). Examples of digital food environments are online grocery stores, smartphone applications for restaurants, fast food delivery and ready-to-eat meal vendors, applications to monitor food consumption and give dietary advise, social media, and video streaming services.

The Grocery Store is a research instrument carefully built to reflect the typical online grocery experience in the United States so as to shed light into the topic. This simulated food environment is an ideal space for minimally invasive interventions, generally accepted by the public (Evers et al., 2018). Most participants found The Grocery Store similar to other online grocery stores. This pilot provided us with rich data to build a full randomized control trial.

6. Conclusion

Although experiments cannot replace real-life experiences, The Grocery Store is sufficiently similar to real online stores for externally valid research and has the potential to help scientists gain insights into consumer behavior. This pilot study further showed that gamification could facilitate healthier food choices. Modifying the characteristics of digital food environments can potentially improve the nutritional quality of food choices and, consequently, food consumption at a large scale (De Bauw et al., 2021; Swinburn et al., 2011).

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Declaration of interest

Declarations of interest: none.

Ethics approval and consent to participate

The Social, Behavioral, and Educational Research Institutional Review Board of Tufts University (IRB #00001070) approved this study on 1/28/2021. Additionally, Duke University Campus Internal Review Board (IRB), Reference number 2021-0276, granted ethical approval for the involvement of human subjects on 05/19/2022. Electronic consent was obtained from each participant. Our work follows the Declaration of Helsinki and the Recommendation for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals.

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Availability of data and materials

Deidentified individual participant data collected in this experiment will be shared upon reasonable request. Proposals may be submitted up to 36 months after article publication. After 36 months, the data will be available at Tufts University Dataverse but without investigator support other than deposited metadata.

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Figure 1: An example showing eight products from the Produce category (aisle) with their crowns.

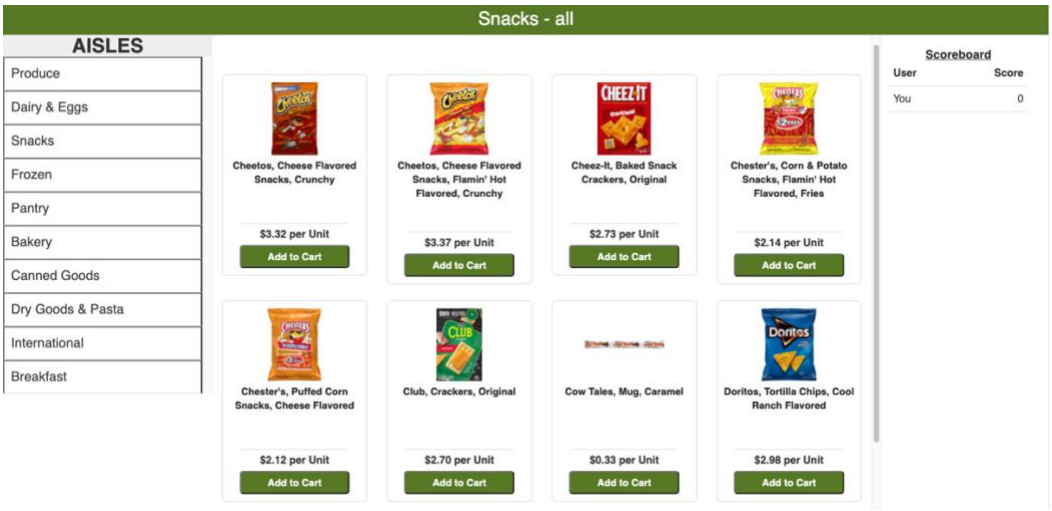

Figure 2: An example showing eight products from the Snacks category (aisle) without crowns.

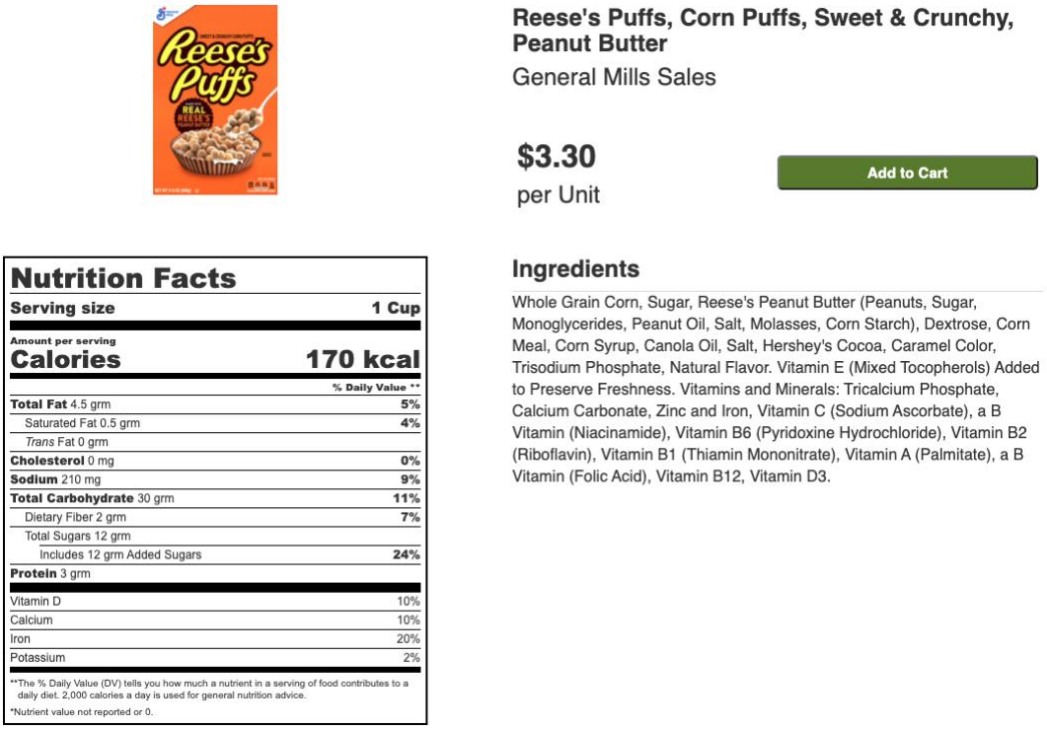

Figure 3: An example of how a product from the Breakfast category (aisle) is displayed in the Grocery Store when the participants from the non-gamified group click on them.

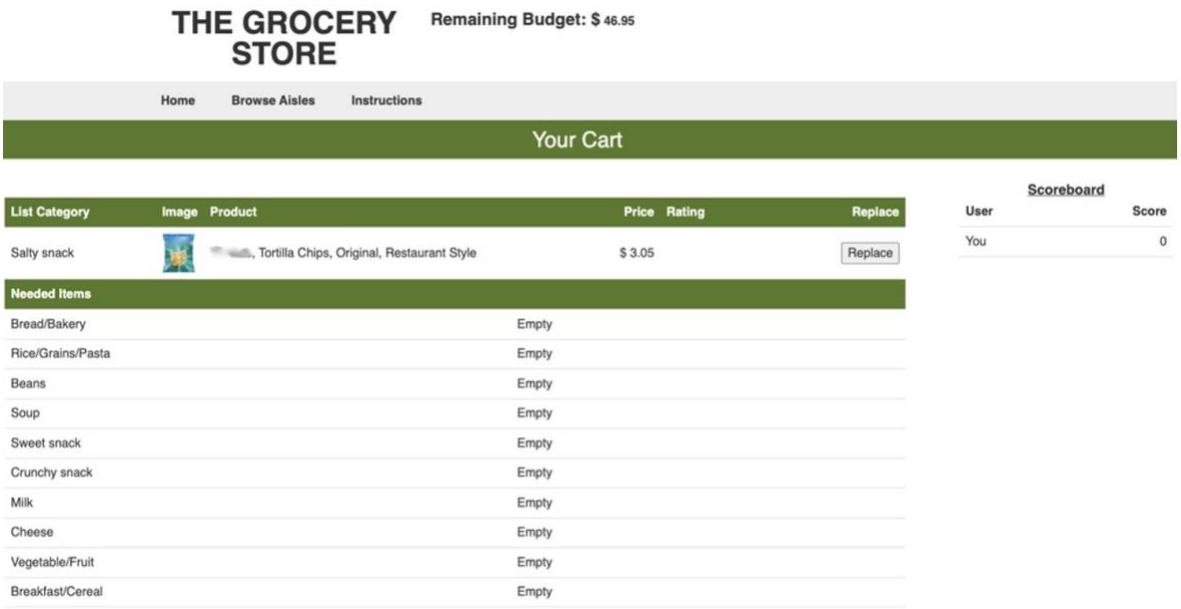

Figure 4: An example of a shopping cart showing one snack included in the snack shopping list item. Selecting this item priced at $3.05 lowered the original budget from $50 to $46.95. The participant could replace the item by clicking “Replace.”

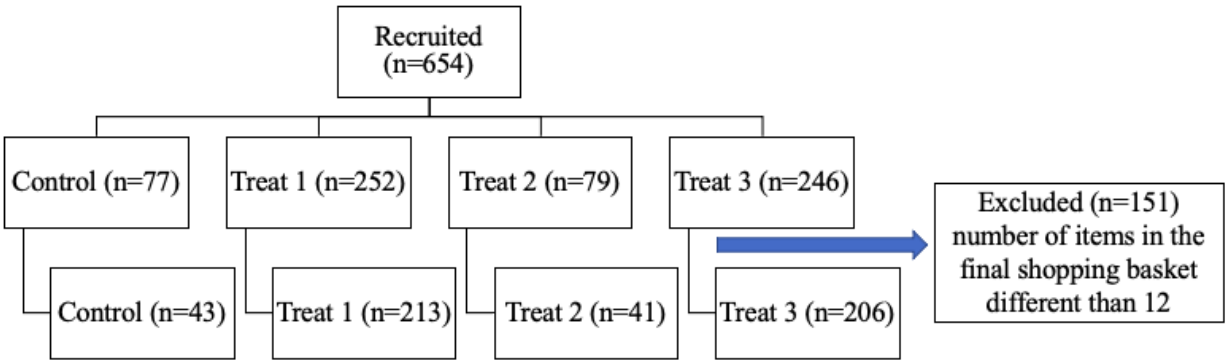

Figure 5: Flow chart. Second row shows the number of participants randomized into each group and third row shows how many had 12 items in the final shopping basket. Those outside the US, or not aged between 18-65 years, or not comfortable reading English, or with an MTurk approval rate lower than 90% were filtered before recruitment.

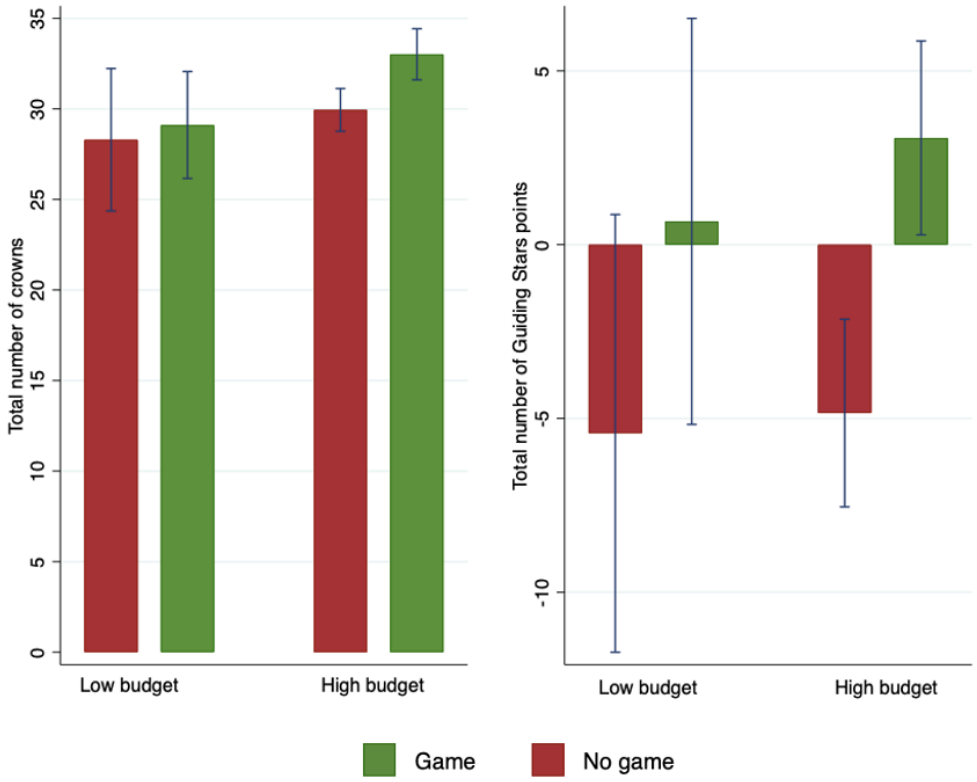

Figure 6: Average and standard deviation of the total number of crowns and total number of Guiding Starts points by game condition and budget constraint.

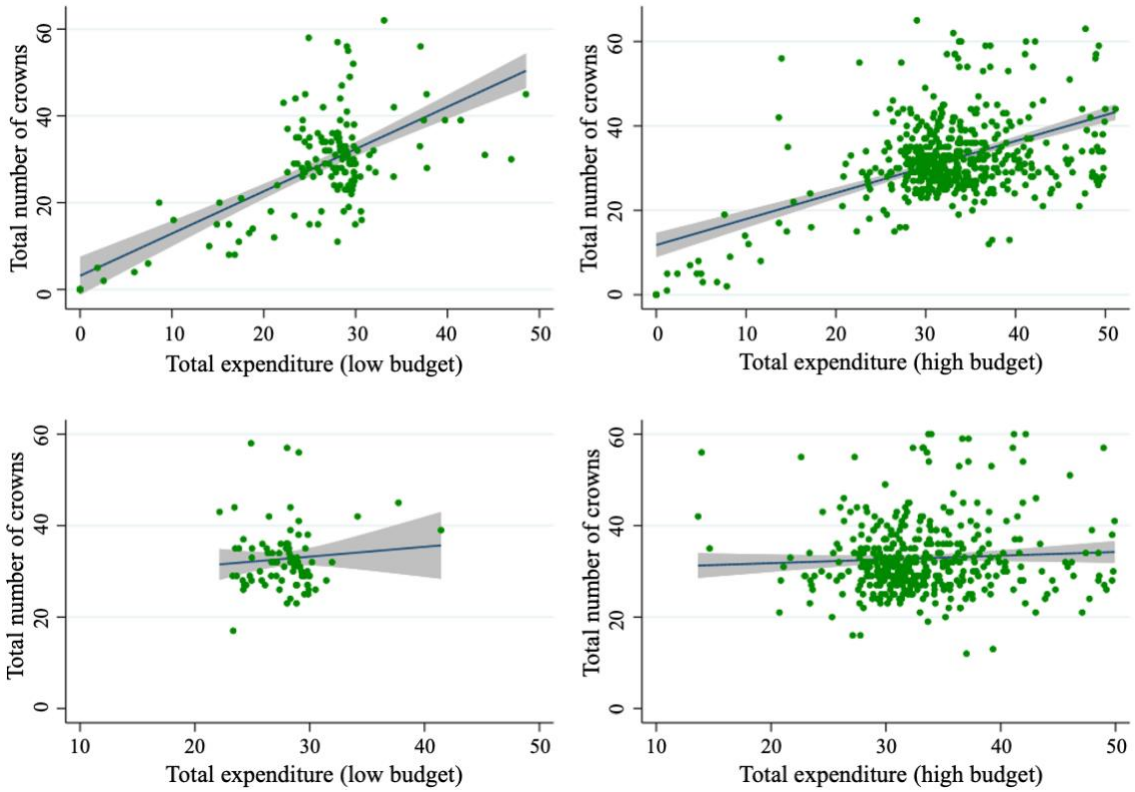

Figure 7: Total expenditure in the experiment correlates with the total number of crowns in the final shopping basket independently of budget for the sample with all participants (charts in the first row; n=654). The correlation diminishes when only those who adhered to the shopping task were included (12 items in the final shopping basket; charts in the second row; n=503).

Table 1: Guiding Stars point system

General foods and beverages points	Meats, poultry, seafood, dairy, and nuts points	Guiding Stars Visual Cues	Grocery Store Crowns
5 to 11	3 to 8	3	5
3 to 4	2	2	4
1 to 2	1	1	3
-2 to 0	0	0	2
≤ -3	0	0	1

The Guiding Stars program has separate rating algorithms for general foods and beverages, and meat, poultry, seafood, dairy, and nuts. The Guiding Stars algorithm has 4 point intervals for its visual cues, giving zero to three Stars. We disaggregated the point interval of -41 to 0 further into -2 to 0 and ≤ -3 for The Grocery Store crowns.

Table 2: Characteristics of participants by study group (n=654)

	Control (n=77)	Treat 1 (n=252)	Treat 2 (n=79)	Treat 3 (n=246)	Total (n=654)
Age (years) (%)					
18-24	1 (1.3)	10 (4.0)	1 (1.3)	8 (3.3)	20 (3.1)
25-34	35 (45.5)	124 (49.8)	42 (53.2)	98 (40.3)	299 (46.1)
35-44	24 (31.2)	77 (30.9)	20 (25.3)	85 (35.0)	206 (31.8)
45-54	13 (16.9)	22 (8.8)	9 (11.4)	31 (12.8)	75 (11.6)
55-64	4 (5.2)	14 (5.6)	6 (7.6)	18 (7.4)	42 (6.5)
65 or more	0 (0.0)	2 (0.8)	1 (1.3)	3 (1.2)	6 (0.9)
Income (%)					
Up to $34,999	21 (27.6)	75 (29.8)	21 (26.6)	59 (24.0)	176 (27.0)
$35,000 to $74,999	33 (43.4)	107 (42.5)	38 (48.1)	122 (49.6)	300 (45.9)
$75,000 or more	22 (28.9)	68 (27.0)	20 (25.3)	63 (25.6)	173 (26.5)
Race/ethnicity (%)					
Black/African American	9 (11.8)	38 (15.1)	11 (13.9)	46 (18.7)	104 (15.6)
Latino/Hispanic	2 (2.6)	4 (1.6)	2 (2.5)	10 (4.1)	18 (2.8)
Asian American	2 (2.6)	23 (9.2)	2 (2.5)	18 (7.3)	45 (6.9)
White/Caucasian	62 (81.6)	179 (71.3)	63 (79.8)	170 (69.1)	474 (72.7)
Other/More than one race	1 (1.3)	7 (2.8)	1 (1.3)	2 (0.8)	11 (1.7)
Gender (%)					
Men	51 (66.2)	162 (64.5)	56 (70.9)	162 (66.1)	431 (66.1)
Women	26 (33.8)	88 (35.1)	23 (29.1)	82 (33.5)	219 (33.6)
Education (%)					
Less than college degree	16 (20.8)	65 (25.8)	24 (30.8)	70 (28.5)	175 (26.8)
College degree or more	61 (79.2)	187 (74.2)	55 (69.6)	176 (72.5)	479 (73.2)
Primary grocery shopper (%)	71 (93.42)	226 (90.0)	75 (94.9)	229 (94.2)	601 (92.6)
Online grocery shopper (%)	50 (64.9)	154 (61.1)	55 (69.6)	142 (57.7)	401 (61.3)
Adherence to the tasks					
Did not exceed the budget	66 (85.7)	251 (99.6)	68 (86.1)	246 (100.0)	631 (96.5)
Purchased exactly 12 items	43 (55.8)	213 (84.5)	41 (51.8)	206 (83.7)	503 (77.4)

Note: SD is for standard deviation. Treat is treatment. The values in the table represent the number of individuals with percentages in parentheses unless otherwise indicated. We collected the self-reported sociodemographic data through a survey administered after participation in the experiment. The Control had a $30 budget and no game (crowns and scoreboard). Treatment 1 participants received a $50 budget and no game. Treatment 2 participants received a $30 budget and the game. Treatment 3 participants received a $50 budget and the game. A “primary grocery shopper” reports being responsible for purchasing their household groceries at least half of the time. “Online grocery shopper” is defined as doing groceries online twice or more per month.

Table 3a: Ordinary least squares model of the effect of the gamification intervention with a budget constraint on the nutritional quality of the final shopping basket as measured by total number of crowns (Full Sample)

	Coefficient	95% CI	P-value	Coefficient	95% CI	P-value
Game	2.53	(0.72; 4.34)	0.006	0.82	(-2.89; 4.52)	0.666
High Budget ($50)	2.78	(0.66; 4.90)	0.01	1.65	(-1.36; 4.66)	0.282
Game X High Budget				2.25	(-1.99; 6.49)	0.297
Constant	27.43	(25.37; 29.49)	<0.001	28.3	(25.66; 30.93)	<0.001
Observations	654			654		
R-squared	0.021			0.023		

Note: The most crowns that a participant could achieve was 60 crowns.

Table 3b: Ordinary least squares model of the effect of the gamification intervention with a budget constraint on the nutritional quality of the final shopping basket as measured by total number of crowns (Restricted Sample)

	Coefficient	95% CI	P-value	Coefficient	95% CI	P-value
Game	3.23	(1.90; 4.56)	<0.001	1.44	(-1.82; 4.70)	0.385
High Budget ($50)	0.09	(-1.69; 1.88)	0.921	-0.96	(-3.45; 1.54)	0.451
Game X High Budget				2.14	(-1.99; 6.49)	0.238
Constant	31.17	(29.42; 32.93)	<0.001	32.05	(29.77; 34.32)	<0.001
Observations	503			503		
R-squared	0.043			0.040		

Note: The most crowns that a participant could achieve was 60 crowns. We restricted the sample to include only participants who selected 12 items for their final shopping basket.

Appendix 1: Number of products in each category and subcategory of the Grocery Store

Category	Frequency	Category	Frequency
Bakery	528	Frozen	204
Bakery desserts	106	Frozen apps and sides	6
Bread	148	Frozen breakfast	17
Breakfast bakery	144	Frozen vegetables	181
Buns and rolls	108	Pantry	154
Tortillas and flat bread	22	Baking ingredients	18
Breakfast	365	Honeys syrups and nectars	24
Breakfast bars and patries	104	Nut butters and jams	112
Breakfast drinks	4	Produce	225
Cereal	207	Fresh fruits	77
Granola	2	Fresh herbs	7
Hot cereal and pancake mixes	48	Fresh vegetables	114
Canned Goods	730	Packaged vegetables and fruits	25
Canned and dried tomatoes	69	Prepared produce	2
Canned and jarred vegetables	149	Snacks	1,727
Canned fruit and applesauce	73	Chips	261
Canned meals and beans	130	Chocolate and candy	224
Canned soup	256	Cookies	161
Dried soup mixes	53	Crackers	187
Dairy & Eggs	628	Energy and granola bars	98
Dairy alternatives	59	Fruit snacks	40
Eggs	13	Multipack chocolate candy	181
Milk	88	Nuts, seeds and dried fruits	78
Packaged cheese	237	Popcorn and jerky	108
Single serving yogurt	114	Pretzels and rice cakes	83
Yogurt	117	Single serving snacks	66
Dry Goods & Pasta	418	Specialty cookies	43
Dry pasta	173	Specialty crackers	74
Grains, rice, and dried goods	177	Tortilla chips	42
Instant foods	68	Trail mix and snack mix	81
International	251		
Hispanic and Latin foods	251		

Appendix 2: The effect of the game and a high budget on the nutritional quality of the final shopping baskets measured by the total number of crowns

	Coefficient	P-value	Coefficient	P-value
Game	2.933	0.001	2.225	0.236
CI	(1.236; 4.630)		(-1.459; 5.909)	
High budget	4.498	0.000	4.044	0.007
CI	(2.424; 6.572)		(1.094; 6.993)	
Game x high budget			0.899	0.671
CI			(-3.252; 5.050)	
Constant	25.49	0.000	25.848	0.000
CI	(23.457; 27.521)		(23.223; 28.472)	
Observations	631		631	
R-squared	0.045		0.045	

Note: Results of OLS regressions on the game's impact on the number of crowns, including only those who spent the initial budget ($30 and $50) or less.

Appendix 3: The effect of the game, high budget, and expenditure on the nutritional quality of the final shopping baskets measured by the total number of crowns

	Coefficient	P-value
Game	9.281	0.012
CI	(2.045; 16.517)	
High budget	9.726	0.001
CI	(3.825; 15.626)	
Game x high budget	-7.549	0.097
CI	(-16.460; 1.362)	
Expenditure	0.458	0.000
CI	(0.259; 0.658)	
Game x expenditure	-0.278	0.038
CI	(-0.539; -0.016)	
High budget x expenditure	-0.375	0.000
CI	(-0.572; 0.177)	
Game x high budget x expenditure	0.314	0.044
	(0.009; 0.619)	
Number of items in the basket	2.343	0.000
	(1.977; 2.710)	
Constant	-9.183	
	(-13.646; -4.627)	
Observations	654	
R-squared	0.5422	

Regression controlled by the number of items in the final shopping basket

Chapter 4: The use of gamification to encourage healthier food selection in online grocery shopping: A randomized controlled trial

[*Under review at Appetite*]

Bianca C. Braga[1], Sean B. Cash[1], Katrina Sarson[1], Remco Chang[2], Ab Mosca[3], and Norbert L. W. Wilson[4]*

[1]Curi.Bianca@tufts.edu; Sean.Cash@tufts.edu; and Katrina.Sarson@tufts.edu; Friedman School of Nutrition Science and Policy, Tufts University, Jaharis 150 Harrison Avenue, Boston, MA, 02111, USA

[2]Remco@cs.tufts.edu; Computer Science, Halligan Hall, Tufts University, 161 College Avenue, Medford, MA 02155, USA

[3] A.Mosca@northeastern.edu; Khoury College of Computer Sciences, Northeastern University, 440 Huntington Avenue, 202 West Village H, Boston, MA 02115, USA

[4] Norbert.Wilson@duke.edu; Divinity School and Sanford School of Public Policy, 304 Gray, 407 Chapel Drive, Duke Box, #90968, Durham, NC 27708-0968, USA

*Corresponding Author

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The use of gamification to encourage healthier food selection in online grocery shopping: A randomized controlled trial

Abstract

Food purchase choices, one of the main determinants of food consumption, is highly influenced by food environments. Given the surge in online grocery shopping as a result of the COVID-19 pandemic, interventions in digital environments present more than ever an opportunity to improve the nutritional quality of food purchase choices. One such way may be through gamification. Participants (n=1,228) shopped for 12 items from a shopping list on a simulated gamified online grocery platform. They were randomized in a 2x2 factorial design: presence vs absence of gamification; high vs. low budget. Participants in the gamification groups saw foods with 1 (least nutritious) to 5 (most nutritious) crown icons as if they were points in a game, and a scoreboard with the total number of crowns collected. Ordinary least squares and Poisson regression models were used in the data analysis to understand the impact of the gamification and budget in the shopping basket quality. In the absence of gamification and low budget, participants collected 30.78 (95% CI [30.27; 31.29]) crowns. In the gamification and low budget condition, participants increased the nutritional quality of their shopping basket by collecting more crowns (B= 4.15, 95% CI [3.55; 4.75], p<0.001). The budget amount ($50 vs. $30) did not alter the final shopping basket (B=0.45, 95% CI [-0.02; 1.18], p=0.057) nor moderated the gamification effect. Gamification increased the nutritional quality of the final shopping baskets and nine of 12 shopping list items. Gamifying online grocery stores may be an effective strategy to improve the nutritional quality of food choices.

Trial registration

The study was implemented according to the protocol prospectively registered at (clinicaltrials.gov ID NCT04919668 “Effect of gamification in an online grocery store”).

Keywords

Online grocery store, food choice, consumer behavior, gamification, nutrition, Guiding Stars

1. Introduction

Consumers have poor ability to accurately interpret numeric nutrition composition from food and beverage labels (food labels) such as the Nutrition Facts Panel (Temple & Fraser, 2014). Front-of-package labeling (FOP) is a standardized provision of nutrition information often in the form of symbols, icons and logos developed to aid interpretation (Shangguan et al., 2019). Nutrient-specific FOP labels inform about specific nutrients, for example warning symbols for excessive content of saturated fat, sugar and sodium (Temple et al., 2020). Summary FOP labels, on the other hand, summarize the healthfulness of foods into a single value or icons such as stars and ticks (Temple et al., 2020). Food labeling has been implemented in a voluntary or mandatory manner to improve the nutrition quality of consumer's food choice, but evidence for their effect is inconclusive (Ceccini & Warin, 2016; Crockett et al., 2018; Kaur et al., 2017).

Barriers to the impact of labels include limited comprehension (Annunziata & Vechhio, 2012), attention (Graham et al., 2012), usage (Wiles et al., 2009), acceptance (Kelly et al., 2009) and awareness (Dumanovsky et al., 2010). An ideal label should be a simple, easy-to-interpret, standardized symbol, of consistent format and location (Institute of Medicine, 2010), complemented by the right choice architecture and a novel technology (Mozaffarian et al., 2012; Afshin et al., 2015; Afshin et al., 2016; Afshin et al., 2017). Gamification is a persuasive technology that can implicitly deliver nutrition and health messages by helping individuals to automatically process information (Baranowski et al., 2016). Gamified environments are designed to attract, capture, and maintain attention (Ritterfeld, Cody, & Vorderer, 2009). Gamification expands intrinsic motivation and engagement using point scoring and progress indicators without giving rise to entire games (Hamari et al., 2017, Mekler et at., 2017, Seaborn & Fels, 2015, McGonigal, 2011). It states clear rules on achieving goals, but it is not necessarily competitive nor needs to award real prizes (Deterding et al., 2011).

This study was done in a gamified simulated online grocery store where all foods displayed had Nutrition Facts Label and ingredient list as required by the Food and Drug Administration (FDA) (FDA, 2022). Part of the participants could see a simple, easy-to-interpret summary label in the form of crown icons (crowns), and a scoreboard. The scoreboard counted the summed number of crowns from all foods included in the

shopping basket, as if the crowns were points from a game (i.e. coins in Super Mario World or gems in Duolingo). Numbers displayed in scoreboards strategically alter behavior, even when participants do not see their intrinsic meaning nor they are tied to rewards (Shen & Hsee, 2017). Gamified environments potentially enhance exposure to interventions (Baranowski et al., 2008).

Participants received one of two budget values to simulate different real-world budget constraints during the shopping task. This is because nutrient-dense foods cost more and lower incomes households consume a diet of worse quality in the US (Drewnowski, 2010; Waterlander et al., 2010). Additionally, healthier foods tend to have higher prices in our store. To the best of our knowledge, gamification has not been used in online grocery shopping yet, but has influenced self-efficacy for preparing and eating fruits and vegetables (Bell et al., 2018; Nour et al., 2019; Yoshida-Montezuma et al., 2020), helped to increase physical activity levels (Winkler, 2019), assisted to improve language test scores (Huynh et al., 2018; Vesselinov & Greco, 2012), between others. We hypothesized that gamification (crowns and scoreboard) and budget influence the nutritional quality of participants' final shopping baskets.

2. Methods

2.1 Settings

Simulated virtual supermarkets are useful and practical tools to investigate the effect of interventions with similar enough results to real world experiences (Mizdrak et al., 2017; Jilcott Pitts et al., 2018; Waterlander et al., 2015; Van Herpen et al., 2016). The Grocery Store is a simulated online grocery store platform developed by a team of computer scientists, economists, and public health nutrition specialists. The Grocery Store has about 5,300 products commonly sold in typical midsized real-life American online grocery stores. They are divided into ten food categories - Bakery, Breakfast, Canned Goods, Dairy & Eggs, Dry Goods & Pasta, International, Frozen, Pantry, Produce and Snacks. Figure 1 shows the gamified Produce page of the Grocery Store with the food categories on the left, scoreboard on the right and crowns at the bottom of each product. More details on the development of the Grocery Store were reported elsewhere (Braga et al., under review). Data access for Nutrition Facts Panel, ingredient

list and price was purchased from Syndigo, a company that owns verified retail product information (Syndigo, n.d.).

Data access for food quality scores was purchased from Guiding Stars, a company that develops a widely used nutrient profiling system (Guiding Stars, n.d.). This system concerns health promotion and disease prevention based on nutrients and other ingestible substances with scientific consensus to aid consumers make healthier food choices (Guiding Stars, n.d.). The Guiding Stars system has been used in academic research at Harvard Univeristy and Tufts University and in real-life supermarkets such as Food Lion and Stop & Shop (Guiding Stars, n.d.). The Guiding Stars nutrient profiling encourages the consumption of vitamins, minerals, fiber, whole grains, omega-3 fatty acids, and monounsaturated fatty acids. It also discourages the consumption of trans fatty acids, saturated fatty acids, added sodium, added sugars, artificial colors, and food dyes (Guiding Stars, 2018). Foods received a score from -41 to +11 points; higher scores represent higher aggregate nutrition and health value. Unhealthy foods receive zero or negative scores, while healthy foods receive positive scores. For example, a sugar-free syrup scored -22 and a baby spinach scored +8 Guiding Stars points. Figure 2 shows the distribution of Guiding Stars by food category. The number of crowns for each food corresponds to their underlying number of points from the Guiding Stars nutrient profiling system. Participants did not see these points, but saw one (least nutritious) to five (most nutritious) crowns for each food. Appendix 1 shows how number of crowns correspond to number of Guiding Stars points. Figure 3 illustrates the percentage of products on offer with one to five crowns by food category.

Figure 1: A gamified Produce page of the Grocery Store. Food categories are displayed on the left and the scoreboard is displayed on the right.

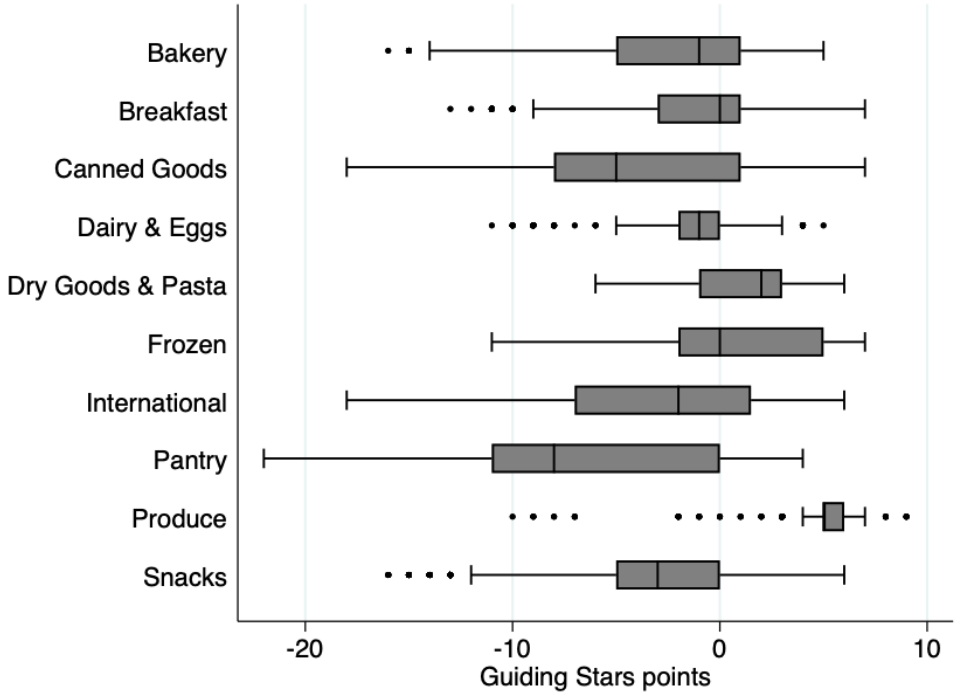

Figure 2: Median and interquartile range of Guiding Stars points by food category displayed in the Grocery Store.

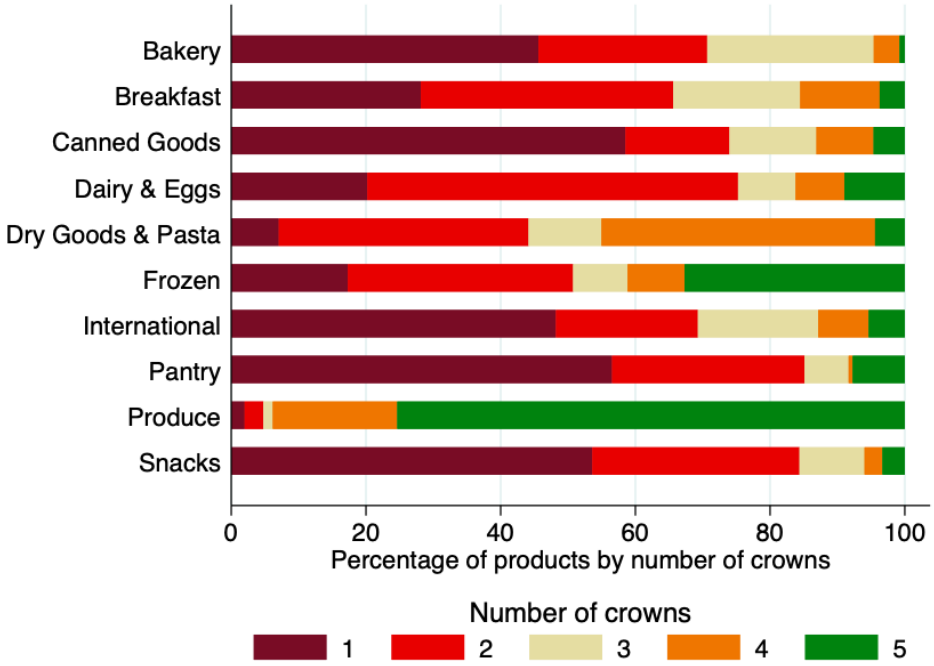

Figure 3: Percentage of products with one to five crowns by food category on offer in the Grocery Store.

2.2 Experimental design and conditions

In this 2x2 full factorial randomized controlled trial, participants were asked to shop for 12 items from a predetermined shopping list. The randomization procedure allocated participants into one of four experimental conditions:

Control: The Grocery Store without game elements and a $30 budget.

Treatment 1: The Grocery Store without game elements and a $50 budget.

Treatment 2: The Grocery Store with game elements (crowns and scoreboards) and a $30 budget.

Treatment 3: The Grocery Store with game elements (crowns and scoreboards) and a $50 budget.

We chose $30 and $50 as budget values to simulate a group that would likely feel more constrained than the other, but would still realistically be able to shop for the 12 food items. The values were based in the results of a pre-pilot test (n=59) with the same experimental conditions and shopping tasks which average expenditure was $30.49 (SE 3.97), median expenditure was $31.23, and the highest expenditure was $48.51.

2.3 Outcomes

The primary outcome was the total number of crowns, defined as the sum of the crowns of foods included in the final shopping basket for each participant. The three secondary outcomes were 1) the number of crowns for each separate shopping list item in the final shopping basket; 2) the sum of the number of Guiding Stars points of all the foods in the final shopping basket; 3) the number of Guiding Stars points for each separate shopping list item in the final shopping basket.

2.4 Sample size and inclusion criteria

We calculated the sample size in G*Power for fixed effects regression models with three coefficients based on 90% power, 5% alpha error, and the smallest effect size (1%) found in a previous pilot study (n=654) (Braga et al., under review; Faul et al., 2007; Faul et al., 2009). The calculated sample size was n=1,053, but we targeted recruitment at n=1211 to account for a potential loss of follow up of 15%. We recruited through Prolific, an online research platform where potential participants are pre-screened, rated by researchers for the quality of their answers and excluded by the platform when data quality is consistently not high. Prolific potential participants have profiles with socio-economic and demographic characteristics, and receive an email from the platform suggesting participation when researchers are looking for participants with their characteristics. For example, we specifically set data pools for Black and Hispanic individuals to avoid underrepresentation, a common problem in the nutrition and health literature (Prolific, 2021; Downing et al., 2016; Kim et al., 2008). The recruitment closed after reaching n=1,200, because data from an experiment ran on the same day with 32 participants to examine the integration of Prolific, The Grocery Store, and Qualtrics were also included (Prolific, 2021; Qualtrics, 2021). After completing the shopping task, participants were redirected to a Qualtrics questionnaire about socioeconomic characteristics, grocery shopping habits, and acceptability of the Grocery Store. (Qualtrics, 2021). A total of n=1,228 were assessed for eligibility.

The inclusion criteria were 1) being 18 to 65 years with an income of up to $69,000 per year; 2) having access to a personal computer, laptop, tablet, or mobile phone; 3) being physically present in the US when participating in the experiment; 4) having 12 items in the final shopping basket, as instructed; 5) not having four or more

items from the same food subcategory in the final shopping basket; and 6) spending 120% or less of the assigned budget. Criterion one was based on the median income of the US (US Census Bureau, 2021). Criterion four ensured that the correlation between the nutritional quality of final shopping baskets and gamification or budget was not due to the number of items included in the final shopping basket. Criteria five was an attempt to eliminate participants that would have potentially completed the task without searching for products they often purchase in real-life shopping trips. Participant who followed the instruction unlikely would choose four or more foods out of 12 shopping list items from only one out of the 54 subcategories (see the shopping task section below). Criterion six was to keep the task realistic, since shoppers sometimes pass their budget a few dollars (Van Ittersum et al., 2010). Figure 4 shows the CONSORT flow diagram and Appendix 2 shows the CONSORT 2010 checklist (Schulz et al., 2010).

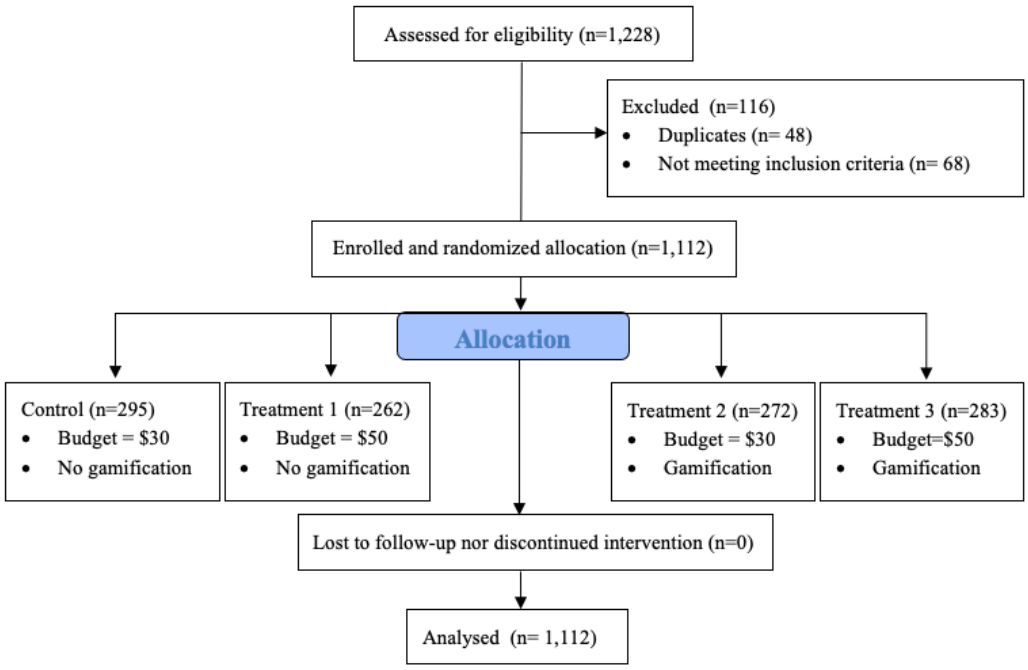

Figure 4: CONSORT flow diagram

2.5 Shopping task

After randomization, participants consented electronically, confirmed that they were in the US, and then proceeded to the Grocery Store. The consent stated "There are elements within the online grocery store that may be manipulated to impact the shopping

environment, and we are testing if this changes your shopping experience." The consent made no reference about how the crowns or the scoreboard could affect participants' behavior. Participants saw the following instructions:

> *Your task today is to go shopping for food for yourself, your family, or whomever you usually shop for. You must shop for 12 items from a shopping list that we will provide (beans, bread/bakery, breakfast/cereal, cheese, eggs, crunchy snack, milk, rice/grains/pasta, soup, sweet snack, salty snack, vegetable/fruit). When you add a food to your shopping cart, you will be asked to assign it to a list item. To review selected and needed items, click on "Cart" in the top menu bar, as shown in the image below. In addition, you can exchange, replace, or remove items from your cart at any time by clicking on "Cart" in the top menu bar, and then selecting "Replace" next to the item you want to exchange, replace, or remove. You will have a budget. This information will show on the top of the page.*

Participants in Treatments 2 and 3 received further information about the presence of crowns displayed for each food item in the Grocery Store:

> *In addition, as you shop, you will see crowns displayed on food items to indicate the following: 1 crown (least nutritious) to 5 crowns (most nutritious).*

The instructions encouraged participants to select food items commonly bought in their real-life shopping trips, and assign them to one of the cart's shopping list items according to eating habits. In practice, they could choose any food for each shopping list item. For example, participants could add a bag of potato chips or an apple as a crunchy snack; a tomato or a pasta as a soup. As participants placed products in their shopping carts, the computer subtracted the cost from the budget and displayed the remaining budget on the screen. Although the shopping list had 12 items, participants were free to buy fewer than that. Some selected more than 12 items potentially due to errors generated by pressing the back button or poor internet connection.

2.6 Statistical analysis

Ordinary least square (OLS) models were used to test the impact of gamification, budget, and the interaction between gamification and budget on the quality of the final shopping basket measured by number of crowns and Guiding Stars points. OLS models were also used to analyze the effect of gamification on the nutritional quality of the 12 items on the grocery list separately, measured by Guiding Stars points. Poisson models were used to test the same relationship but using number of crowns as an outcome. The statistical analyses was conducted in Stata 16.1/IC (Stata, 2019).

The study was performed according to the Declaration of Helsinki and approved by the Social, Behavioral and Educational Research Institutional Review Board of Tufts University (IRB #00001028) with additional approval from Duke University Campus IRB (# 2021-0276). Electronic consent was obtained from each participant of the trial. The hypotheses and the analytic plan were pre-specified before the data were collected, and preregistered at clinicaltrails.gov (ID NCT04919668 "Effect of Gamification in an online grocery store") and aspredicted.com (ID #67034).

3. Results

Out of the n=1,228 selected individuals, 48 were excluded for duplicated participation (Figure 4). The inclusion criteria was not met by 68 individuals, of which 58 bought a number of products different than 12, and 10 bought four or more products from the same subcategory. No one spent more than the original budget. The eligible 1,112 participants were randomized using math random function of JavaScript to one of the four experimental conditions (JavaScript, n.d.). According to t-test results, baseline characteristics were similar between groups, so randomization was successfully achieved. Table 1 summarizes the characteristics of the participants, and Table 2 summarizes their grocery shopping habits and acceptance of the Grocery Store. Figure 5 shows the percentage of food choices made by participants across all conditions for shopping list items from each food category. Most participants selected foods for the shopping list that matched the Grocery Store food category (e.g., Bakery for breads and bakery). Participants selected products from a greater diversity of categories for beans and sweet snacks.

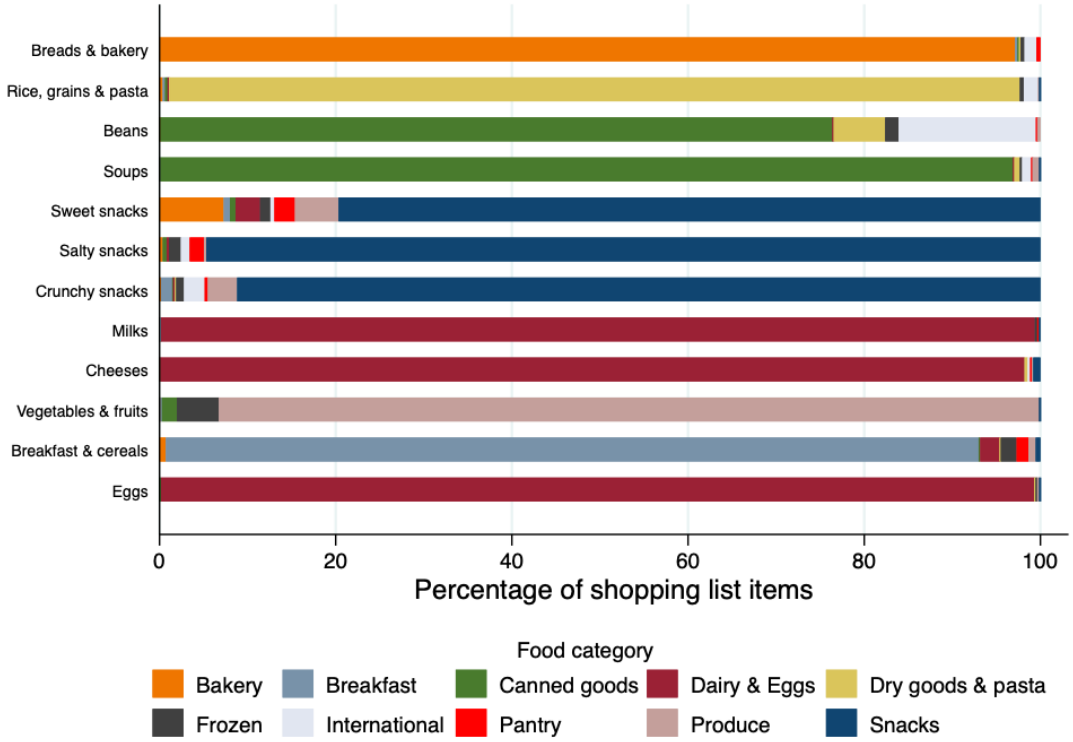

Figure 5: Percentage of food choices made by participants across all conditions for shopping list items from each food category from the Grocery Store.

<<Table 1 placed near here>>

<<Table 2 placed near here>>

Participants were, on average (standard deviation), 30 (10) years old. Nearly all (92.3%) were primary grocery shoppers, and 40.6% shopped for groceries online at least once a month. Females (as opposed to males and others) were 68.1% of the sample, racial/ethnic minorities were 59.4%, participants in food assistance programs (SNAP and WIC) were 19.8%, and 45.5% had at least a college degree. About 96% of participants in the gamified groups stated that they had noticed the crowns, while 79.1% correctly indicated the purpose of the crowns. More than half (57.5%) of the sample considered their experience in the Grocery Store similar or better than their real-life online grocery experiences.

The average total number of crowns in the final shopping basket of the control group was 30.84 (SD 3.73). Participants in the no gamification and high budget condition

had, on average, 31.29 (SD 4.04) crowns, the gamification and low budget group had 34.87 (SD 5.85) crowns, and the gamification and high budget had 35.57 (SD 6.19). The lowest number of crowns the participant could collect for a complete basket was 12, and the highest number was 60. Table 3 shows the results of the regressions measuring the impact of gamification and high budget on the quality of the final shopping basket and each shopping list item separately according to the total number of crowns and Guiding Stars points. The estimated effect of gamification increased the total number of crowns by 4.15 (95% CI [3.55; 4.75]; p<0.001). Gamification also led to statistically significant improvements in the number of crowns associated with 9 of the 12 shopping list categories, with null effect for eggs (B=1.01, 95% CI [0.95; 1.07], p=0.761), cheese (B=1.05, 95% CI [0.96; 1.14], p=0.297) and vegetables and fruits (B=1.02, 95% CI [0.97; 1.08], p=0.457). The highest significant impact of gamification on the number of crowns was 1.36 (95% CI [1.23; 1.50]; p<0.001) for soups, an improvement of 109.70% compared to the control group, while the lowest was 1.09 (95% CI [1.02; 1.16], p=0.012) crowns for rice, grains, and pasta, an increase of 35.27%. Appendix 3 shows the models' results with interaction terms between gamification and high budget, that were not statistically significant to explain the total number of crowns.

<<Table 3 placed near here>>

The average total number of Guiding Stars points in the final shopping basket of the control group was -7.38 (SD 10.60). Participants in the no gamification and high budget condition had an average of -6.73 (SD 11.59) points; the gamification and low budget group had 2.36 (SD 15.51) points, and the gamification and high budget had 3.87 (SD 16.10). The final shopping basket with 12 items could have from -264 to 132 Guiding Stars points. Gamification increased the total number of Guiding Stars points in the final shopping basket by 10.16 (95% CI [8.56; 11.77], p<0.001) compared to no gamification. There was improvement in food choice for all shopping list items but vegetables and fruits (B=0.18, 95% CI [-0.06; 0.43], p=0.141), and eggs (B=0.04, 95% CI [-0.01; 0.08], p=0.091) when measured by Guiding Stars points. The control group purchased unhealthy soups (constant=-7.78), sweet snacks (constant=-5.08), salty snacks (constant=-1.48), crunchy snacks (constant=-1.44), and cheese (constant=-2.33) according to the constant of the regression measured by Guiding Stars points.

The effect of the high budget on the quality of the final shopping basket measured by crowns was not statistically significant at the 5% level (p = 0.057), but increased the number of crowns of salty snacks by 1.09 (95% CI [1.00; 1.18]; p=0.038), a 35.9% improvement in relation to the control. According to Guiding Stars points, the improvement for salty snacks was B=0.37 (95% CI [0.09; 0.66], p=0.011), for bakery was B=0.34 (95% CI [0.09; 0.60], p=0.009), and for rice, grains & pasta was B=0.37 (95% CI [0.10; 0.64], p=0.008).

4. Discussion

Food environments play a major role on grocery shopping decisions (Hall, 2018; Swinburn et al., 1999; Swinburn et al., 2011). Our findings give insights on the effect of gamification and budget on food choices in a simulated online grocery store. The novel form of food labeling aided by a dynamic scoreboard increased the nutritional quality for all shopping list items except for cheese, eggs, and vegetables and fruits when measured by number of crowns. We detected more changes in food quality measured by Guiding Stars points than by crowns since the former is more granular than the latter. Vegetables and fruits and eggs were the only shopping list items which gamification led to insignificant changes in Guiding Stars points. This is because 94% of choices for vegetables and fruits were from the Produce category, that had the highest average number of Guiding Stars points (4.85 (SD 2.45)), the narrowest interquartile range (5;6 points) and the highest percentage (82.8%) of products with five crowns. Ninety eight percent of egg choices came from Dairy & Eggs, the category with the second narrowest interquartile range (-3;0 points). The largest improvements led by gamification were in the shopping list items with the most unhealthy choices among the control group, soups (constant= -7.78) and sweet snacks (constant= -5.08). There was no difference in the overall healthfulness of the final basket between low and high budget groups, nor budget moderated the effect of gamification. The high budget was associated with healthier food choices for three out of 12 shopping list items, for two of which the control group was already making healthy choices.

Nutrition information provided to shoppers in online retail environments remains inconsistent both across retailers, and between online and physical stores (Pomeranz et al., 2022; Headrick et al., 2021). Yet, products in our store consistently displayed verified

Nutrition Facts Panel and ingredient list to all participants. Nutrition Facts Panel and ingredient list require reflection, analysis, and conscious choice from shoppers, and depend on engagement and motivation (Sanjari, Jahn & Boztug, 2017). The cognitive process underlying their use involves attention, memory, nutrition knowledge and comprehension (Miller & Cassady, 2015). In reality, consumers often make purchases based on snap decisions founded on automatic reactions shaped by environmental cues (Marteau et al., 2011). They rely on fast and simple heuristics to satisfy food preferences without having to think about tradeoffs (Schulte-Mecklembeck et al., 2013; Scheibehenne et al., 2007).

Accordingly, three assumptions may explain our results. First, gamification may have raised the attention to food quality, independently of nutrition knowledge. The crowns were large, displayed in frontal position and were almost monochromatic, features that raise attention to nutrition labels (Bialkova & Trijp, 2010). The dynamic changes of the scoreboard for every food added or deleted from the shopping basket may have drawn attention to the nutrition quality of the whole basket throughout the experiment. Studies have associated self-reported nutrition knowledge and attention to labels (Cooke & Papadaki, 2014; Norazlanshah et al., 2013), but gamification may have dissociated these variables since knowledge was unnecessary to interpret the crowns and scoreboard. More than 80% of participants in the crowns and scoreboard groups understood their meaning and purpose. Second, gamification may have increased nutrition fluency, "a metacognitive feeling of ease" (Dhar & Gorlin, 2013). The labels were in central position and visual clutter was minimized in the surroundings, features that facilitate usage of nutrition labels (Graham et al., 2012). The label design and scoreboard allowed simplifying heuristics to aid participants quickly comprehend the difference in nutritional quality of food items (Graham et al., 2012). Typically, consumers spend only a few seconds examining labels before selecting foods (Sanjari, Jahn & Boztug, 2017). Third, the increase in nutrition fluency may have held even for the low budget group, that had one extra restriction to think about while accomplishing the task. Fatigue, multitasking and high number of alternatives builds up cognitive load and harms the ability to encode external signals, including for food choice (Cohen & Babey, 2012; Becker et al., 2015).

The strengths of this study are the shopping environment and the sample characteristics. The Grocery Store mimicked web designs and had the most sold food products from midsized real-life US grocery stores (Braga et al., under review). The Guiding Stars system have based food labels that successfully improved consumer's food choice in real-life brick-and-mortar US grocery stores (Fischer et al., 2011; Guiding Stars, 2018; Rahkovsky et al., 2013; Sutherland et al., 2010). The large multi ethnic/racial sample was composed of primary grocery shoppers from low- and middle income households located across rural, suburban and urban areas used to shopping for groceries online. Understanding if gamification would work for this income group was important because income is negatively associated with dietary quality in US households (US Department of Health and Human Services, 2021; French et al., 2019). We actively recruited a relevant percentage of ethnic/racial minorities since they bear the highest burden of food injustice (Morales et al., 2021; US Census Bureau, 2021), but are underrepresented in nutrition studies. Another strength of the study was that participants maintained their autonomy because the experimental design did not restrict any food choice.

The main limitation of our study is that it was a hypothetical exercise – participants did not use their own money, nor received the food products chosen in the Grocery Store. Future studies should verify if participants exhibit similar behavior when making real food purchases with their own money and if this behavior persists after repeated online grocery shopping events. Ideally, the meaning of the crowns would not have had to be explained in words before the experiment started. Despite no intrinsic meaning in nutrition and health, crowns could become familiar and meaningful with repeated shopping trips (Bialkova & Trijp, 2010; McDougall et al., 2016; Shen et al., 2020). Finally, almost 30% of the sample found the experience in the Grocery Store less satisfactory than in real-life online grocery stores.

5. Conclusion

The COVID-19 pandemic drastically expanded the importance of online grocery shopping for individuals of all levels of income (Ellison et al., 2021). For multiple reasons, the nutritional quality of food purchased by American households is worse than recommended (Mancino et al., 2018). Gamifying online grocery shopping can encourage

a healthier purchase behavior especially for typically unhealthy shopping list items, independent of budget.

6. List of abbreviations

CI	confidence interval
COVID-19	coronavirus disease
CONSORT	Consolidated Standards of Reporting Trials
OLS	ordinary least squares
SD	standard deviation
SNAP	Supplemental Nutrition Assistance Program
US	United States
WIC	Special Supplemental Nutrition Program for Women, Infants, and Children

7. Supplementary Information

CONSORT Checklist

8. Consent for publication

Not applicable.

9. Availability of data and materials

Deidentified individual participant data collected in this experiment will be shared upon reasonable request. Proposals may be submitted up to 36 months after article publication. After 36 months, the data will be available at Tufts University Dataverse but without investigator support other than deposited metadata. A formal data sharing agreement should be signed. Experimental data were managed and stored at a secure Tufts University server.

10. Declaration of interest

None.

11. Funding

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12. Authors' contributions

BCB, NW, and SBC designed the experiment and wrote the statistical analysis plan, IRB submission, and ClinicalTrials.gov registration. KS contributed to the IRB submission. AM and RC designed and constructed The Grocery Store with BCB, KS, and NW inputs. BCB, AM, and RC collected the data. BCB led the analysis and wrote the initial draft of the manuscript, with contributions from all authors. BCB, NW, and SBC revised the manuscript, and all authors reviewed the final version.

13. Acknowledgments

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Table 1. Sociodemographic characteristics of the sample

Characteristics	Control (n=295)	Treat 1 (n=262)	Treat 2 (n=272)	Treat 3 (n=283)
Age (years) (mean±SD)	30.6±10.6	29.9±10.5	30.2±10.4	30.2±9.8
Income (N (%))				
Up to $39,999	199 (69.1)	168 (66.1)	170 (64.2)	173 (62.2)
$40,000 to $69,999	80 (27.8)	80 (31.5)	86 (32.5)	95 (34.2)
$70,000 or more	9 (3.1)	6 (2.36)	9 (3.4)	10 (3.6)
Race/ethnicity (N (%))				
Black/African American	64 (21.7)	56 (21.5)	83 (31)	77 (27.2)
Latino/Hispanic	75 (25.4)	65 (24.9)	57 (21.3)	88 (31.1)
Asian American	11 (3.7)	7 (2.7)	10 (3.7)	4 (1.4)
White/Caucasian	125 (42.4)	120 (46.0)	106 (39.6)	99 (35)
Other	20 (6.8)	13 (5)	12 (4.5)	15 (5.3)
Gender (N (%))				
Male	85 (28.8)	77 (29.5)	75 (27.6)	88 (31.1)
Female	206 (69.8)	174 (66.8)	189 (69.5)	188 (66.4)
Other	4 (1.4)	10 (3.8)	8 (2.9)	7 (2.5)
Education (N (%))				
Up to high school/GED	47 (16)	54 (20.7)	38 (14)	34 (12.1)
Associate or technical degree	38 (13)	30 (11.5)	33 (12.1)	31 (11)
Some college	82 (27.9)	61 (23.4)	76 (27.9)	81 (29)
College degree or more	127 (43.2)	116 (44.4)	125 (46)	136 (48.2)
Household area (N (%))				
Urban	111 (39)	94 (36.9)	104 (39.3)	124 (45.3)
Suburban	123 (43.2)	121 (47.5)	112 (42.3)	122 (44.5)
Rural	51 (17.9)	40 (15.7)	49 (18.5)	28 (10.2)
Number of people in HH (mean±SD)	2.8±1.5	2.7±1.5	2.6±1.3	2.5±1.3
Number of children in HH (mean±SD)	0.5±0.9	0.52±0.9	0.4±0.7	0.4±0.8
Primary grocery shopper (N (%))	267 (90.5)	240 (91.6)	252 (92.7)	264 (93.3)
Online grocery shopping at least 1/month (N (%))	123 (42.0)	98 (37.6)	108 (39.9)	120 (42.6)

Note: SD is standard deviation; N is number; GED is general education development; HH is household. Control: no gamification and a $30 budget. Treatment 1: no gamification and a $50 budget. Treatment 2: with gamification (crowns and scoreboards) and a $30 budget. Treatment 3: with gamification (crowns and scoreboards) and a $50 budget. Groups were similar at baseline.

Table 2. Survey about the design and acceptability of the Grocery Store

Characteristics	Control (n=295)	Treat 1 (n=262)	Treat 2 (n=272)	Treat 3 (n=283)
Time taken to complete the experiment (N (%))				
Use shopping list in real life	227 (77.0)	193 (73.7)	208 (76.8)	208 (73.5)
Found the foods in the store they usually buy	221 (74.9)	217 (82.9)	197 (72.7)	222 (78.5)
Noticed crowns	20 (6.8)	13 (5.0)	262 (96.7)	272 (96.1)
Swapped foods because of crowns	4 (20)	0 (0)	113 (43.1)	114 (41.9)
Purpose of crown (Choose 1) (N (%))				
To indicate popular foods	1 (5)	3 (23.1)	10 (3.8)	9 (3.3)
To indicate nutritional value	6 (30)	4 (30.8)	214 (81.7)	225 (82.7)
To indicate attempt of promotion	4 (20)	0 (0)	10 (3.8)	10 (3.7)
To indicate some other benefit	5 (25)	2 (15.4)	11 (4.2)	9 (3.3)
I don't know	4 (20)	4 (30.8)	17 (6.5)	18 (6.6)
Acceptance of the Grocery Store for (N (%))				
Finding foods	201 (68.1)	177 (67.8)	181 (67.3)	209 (73.9)
Selecting foods	232 (78.9)	202 (77.4)	214 (79.0)	227 (80.2)
Placing foods in the basket	238 (81.0)	201 (77.6)	229 (85.1)	237 (83.8)
Completing the shopping list	236 (80.3)	195 (74.7)	214 (79.0)	230 (81.3)
Checking out	238 (80.7)	196 (75.7)	229 (84.5)	235 (83.0)
Acceptance of the time taken	234 (79.3)	210 (80.2)	216 (79.7)	234 (82.7)
Acceptance of budget (Choose 1) (N (%))				
Not enough money	101 (34.2)	9 (3.4)	89 (32.8)	12 (4.2)
The right amount of money	187 (63.4)	162 (61.8)	178 (65.7)	199 (70.3)
Too much money	6 (2)	87 (33.2)	4 (1.5)	70 (24.7)
Compared with past online grocery shopping experiences (Choose 1) (N (%))				
The Grocery Store was worse	104 (35.3)	80 (30.5)	78 (28.8)	80 (28.3)
The Grocery Store was the same	112 (38.0)	104 (39.7)	107 (39.5)	117 (41.3)
The Grocery Store was better	39 (13.2)	48 (18.3)	59 (21.8)	49 (17.3)
I have not shopped online before	37 (12.5)	30 (11.5)	25 (9.2)	35 (12.4)

Note: N is number. Control: no gamification and a $30 budget. Treatment 1: no gamification and a $50 budget. Treatment 2: with gamification (crowns and scoreboards) and a $30 budget. Treatment 3: with gamification (crowns and scoreboards) and a $50 budget.

Table 3: Effect of gamification on crowns and Guiding Stars points

	Gamification			High Budget			Constant			
Outcomes	B	95% CI	P-value	B	95% CI	P-value	B	95% CI	P-value	R-squared
Total number of crown	4.15	(3.55; 4.75)	**<0.001**	0.58	(-0.02; 1.18)	0.057	30.78	(30.27; 31.29)	**<0.001**	0.148
Number of crowns by list item										
Bakery	1.19	(1.11; 1.27)	**<0.001**	1.05	(0.99; 1.13)	0.120	2.70	(2.54; 2.87)	**<0.001**	0.008
Rice, Grains & Pasta	1.09	(1.02; 1.16)	**0.012**	1.05	(0.98; 1.12)	0.168	3.09	(2.92; 3.27)	**<0.001**	0.002
Beans	1.13	(1.06; 1.21)	**<0.001**	1.03	(0.96; 1.10)	0.438	2.70	(2.54; 2.86)	**<0.001**	0.004
Soup	1.36	(1.23; 1.50)	**<0.001**	1.03	(0.93; 1.13)	0.594	1.24	(1.13; 1.35)	**<0.001**	0.013
Sweet snacks	1.30	(1.18; 1.44)	**<0.001**	0.99	(0.90; 1.09)	0.837	1.32	(1.21; 1.44)	**<0.001**	0.009
Salty snacks	1.19	(1.10; 1.29)	**<0.001**	1.09	(1.00; 1.18)	**0.038**	1.95	(1.82; 2.09)	**<0.001**	0.007
Crunchy snacks	1.21	(1.12; 1.31)	**<0.001**	1.05	(0.97; 1.13)	0.225	1.91	(1.78; 2.05)	**<0.001**	0.007
Milk	1.19	(1.11; 1.27)	**<0.001**	1.01	(0.95; 1.08)	0.736	2.77	(2.61; 2.94)	**<0.001**	0.007
Cheese	1.05	(0.96; 1.14)	0.297	0.98	(0.89; 1.07)	0.582	1.77	(1.64; 1.90)	**<0.001**	0.001
Vegetables & Fruits	1.02	(0.97; 1.08)	0.457	1.00	(0.94; 1.05)	0.864	4.68	(4.47; 4.90)	**<0.001**	0.000
Breakfast cereal	1.23	(1.15; 1.32)	**<0.001**	0.97	(0.91; 1.04)	0.399	2.69	(2.53; 2.85)	**<0.001**	0.009
Eggs	1.01	(0.95; 1.07)	0.761	1.00	(0.94; 1.06)	0.919	3.99	(3.79; 4.19)	**<0.001**	0.000
Total number of Guiding Stars points	10.16	(8.56; 11.77)	**<0.001**	1.09	(-0.52; 2.69)	0.186	-7.59	(-8.95; -6.22)	**<0.001**	0.124
Guiding Stars points by list item										
Bakery	0.95	(0.69; 1.21)	**<0.001**	0.34	(0.09; 0.60)	**0.009**	0.74	(0.52; 0.96)	**<0.001**	0.052
Rice, Grains & Pasta	0.53	(0.26; 0.80)	**<0.001**	0.37	(0.10; 0.64)	**0.008**	1.50	(1.27; 1.73)	**<0.001**	0.020
Beans	0.86	(0.52; 1.21)	**<0.001**	0.12	(-0.22; 0.47)	0.482	0.57	(0.28; 0.87)	**<0.001**	0.022
Soup	2.45	(1.90; 2.99)	**<0.001**	0.13	(-0.42; 0.68)	0.640	-7.78	(-8.24; -7.32)	**<0.001**	0.066
Sweet snacks	1.15	(0.64; 1.66)	**<0.001**	0.05	(-0.46; 0.56)	0.846	-5.08	(-5.51; -4.65)	**<0.001**	0.018
Salty snacks	0.83	(0.54; 1.12)	**<0.001**	0.37	(0.09; 0.66)	**0.011**	-1.48	(-1.73; -1.24)	**<0.001**	0.035
Crunchy snacks	0.74	(0.43; 1.05)	**<0.001**	0.19	(-0.13; 0.50)	0.243	-1.44	(-1.71; 1.18)	**<0.001**	0.021
Milk	0.71	(0.45; 0.98)	**<0.001**	0.03	(-0.23; 0.29)	0.824	0.46	(0.24; 0.69)	**<0.001**	0.025
Cheese	0.13	(0.32; 0.24)	**0.010**	0.00	(-0.10; 0.10)	0.993	-2.33	(-2.42; -2.24)	**<0.001**	0.006
Vegetables & Fruits	0.18	(-0.06; 0.43)	0.141	-0.20	(-0.44; 0.05)	0.117	5.05	(4.84; 5.26)	**<0.001**	0.004
Breakfast cereal	1.58	(1.18; 1.98)	**<0.001**	-0.30	(-0.69; 0.10)	0.145	0.19	(-0.15; 0.53)	0.271	0.053
Eggs	0.04	(-0.01; 0.08)	0.091	-0.03	(-0.08; 0.01)	0.170	2.01	(1.97; 2.04)	**<0.001**	0.004

Note: Gamification is the presence of crowns and a scoreboard in The Grocery Store. A high budget equals $50. Each separate item had from 1 to 5 crowns corresponding to underlying Guiding Stars points. Ordinary least squares (OLS) regressions were used for the general models, with the total number of crowns and Guiding Stars points as the outcomes. OLS regressions were also used for models where Guiding Stars points were the outcomes for individual list items. Poisson regressions used for the models in which outcomes were individual list items measured by crowns. R-squared is a pseudo R-square for Poisson regressions. P-values in bold are significant at the 5% level or less.

Appendix 1: The number of crowns for the food items present in The Grocery Store and the underlying point scoring system

Guiding Stars® Point Range General Foods and Beverages	Guiding Stars® Point Range Meats, Poultry, Seafood, Dairy, and Nuts	Number of Guiding Stars® Stars	Number of Crowns All food items
5 to 11	3 to 8	3	5
3 to 4	2	2	4
1 to 2	1	1	3
-2 to 0	0	0	2
≤ -3	0	0	1

Note: The Guiding Stars® framework divides foods and beverages into four groups. The products in The Grocery Store fit into two of these four groups: General Foods and Beverages, and Meats, Poultry, Seafood, Dairy and Nuts. Each of these groups is made up of different intervals associated with specific numbers of Guiding Stars Stars. These Stars illustrate the different degrees of healthiness of products. Products with less than one point are deemed unhealthy in the Guiding Stars framework. The Grocery Store displayed one or two crowns for unhealthy products, and three to five crowns for healthy products.

Appendix 2: Effect of gamification, high budget and gamification with high budget on crowns and Guiding Stars points

Outcomes	Gamification			High Budget			Gamification * High Budget			Constant		
	B	95% CI	P-value	B	95% CI	P-value	B	95% CI	P-value	B	95% CI	P-value
Total number of crowns	4.03	(3.19; 4.86)	**<0.001**	0.45	(-0.39; 1.30)	0.292	0.25	(-0.94; 1.45)	0.679	30.84	(30.26; 31.42)	**<0.001**
Number of crowns by list item												
Bakery	1.22	(1.11; 1.34)	<0.001	1.08	(0.98; 1.20)	0.112	0.95	(0.83; 1.09)	0.463	2.66	(2.48; 2.86)	<0.001
Rice, Grains & Pasta	1.11	(1.01; 1.22)	0.026	1.07	(0.97; 1.17)	0.157	0.96	(0.84; 1.09)	0.543	3.06	(2.87; 3.27)	<0.001
Beans	1.11	(1.00; 1.22)	0.037	1.00	(0.91; 1.11)	0.915	1.04	(0.91; 1.20)	0.560	2.73	(2.54; 2.92)	<0.001
Soup	1.35	(1.17; 1.55)	<0.001	1.02	(0.88; 1.18)	0.839	1.02	(0.84; 1.24)	0.850	1.24	(1.12; 1.38)	<0.001
Sweet snacks	1.22	(1.07; 1.40)	0.003	0.92	(0.79; 1.06)	0.243	1.14	(0.94; 1.39)	0.170	1.37	(1.24; 1.51)	<0.001
Salty snacks	1.19	(1.06; 1.33)	0.002	1.08	(0.97; 1.22)	0.171	1.00	(0.86; 1.18)	0.966	1.95	(1.80; 2.12)	<0.001
Crunchy snacks	1.24	(1.11; 1.39)	<0.001	1.08	(0.96; 1.22)	0.207	0.95	(0.81; 1.12)	0.547	1.89	(1.74; 2.05)	<0.001
Milk	1.20	(1.09; 1.32)	<0.001	1.03	(0.93; 1.14)	0.595	0.97	(0.85; 1.11)	0.680	2.75	(2.57; 2.95)	<0.001
Cheese	1.04	(0.92; 1.18)	0.501	0.97	(0.86; 1.10)	0.643	1.01	(0.85; 1.20)	0.913	1.77	(1.62; 1.93)	<0.001
Vegetables & Fruits	1.02	(0.94; 1.10)	0.675	0.99	(0.92; 1.07)	0.814	1.01	(0.91; 1.12)	0.872	4.69	(4.45; 4.94)	<0.001
Breakfast cereal	1.20	(1.09; 1.32)	<0.001	0.95	(0.85; 1.05)	0.280	1.05	(0.91; 1.20)	0.486	2.72	(2.54; 2.92)	<0.001
Eggs	1.00	(0.92; 1.08)	0.985	0.99	(0.91; 1.07)	0.756	1.02	(0.91; 1.15)	0.736	4.00	(3.78; 4.24)	<0.001
Total number of Guiding Stars points	9.74	(7.49; 11.99)	**<0.001**	0.65	(-1.62; 2.93)	0.573	0.86	(-2.35; 4.08)	0.599	-7.38	(-8,94; -5.82)	**<0.001**
Guiding Stars points by list item												
Bakery	1.11	(0.75; 1.47)	**<0.001**	0.50	(0.14; 0.87)	**0.007**	-0.32	(-0.84; 0.19)	0.220	0.67	(0.42; 0.92)	**<0.001**
Rice, Grains & Pasta	0.68	(0.30; 1.06)	**<0.001**	0.52	(0.14; 0.91)	**0.008**	-0.31	(-0.85; 0.23)	0.265	1.43	(1.16; 1.69)	**<0.001**
Beans	0.78	(0.29; 1.27)	**0.002**	0.04	(-0.45; 0.53)	0.876	0.17	(-0.53; 0.87)	0.629	0.61	(0.28; 0.95)	**<0.001**
Soup	2.24	(1.48; 3.00)	**<0.001**	-0.08	(-0.85; 0.69)	0.835	0.42	(-0.67; 1.52)	0.446	-7.68	(-8.2; -7.15)	**<0.001**
Sweet snacks	0.82	(0.10; 1.53)	**0.025**	-0.29	(-1.01; 0.43)	0.428	0.68	(-0.34; 1.70)	0.189	-4.92	(-5.4; -4.4)	**<0.001**
Salty snacks	0.82	(0.41; 1.22)	**<0.001**	0.36	(-0.05; 0.77)	0.083	0.03	(-0.55; 0.61)	0.920	-1.47	(-1.75; -1.19)	**<0.001**
Crunchy snacks	0.85	(0.41; 1.29)	**<0.001**	0.30	(-0.14; 0.74)	0.182	-0.23	(-0.85; 0.39)	0.471	-1.49	(-1.80; -1.19)	**<0.001**
Milk	0.71	(0.34: 1.08)	**<0.001**	0.03	(-0.35; 0.40)	0.884	0.00	(-0.53; 0.53)	0.988	0.46	(0.21; 0.72)	**<0.001**
Cheese	0.12	(-0.02; 0.27)	0.089	-0.01	(-0.15; 0.13)	0.886	0.02	(-0.18; 0.22)	0.833	-2.33	(-2.42; -2.23)	**<0.001**
Vegetables & Fruits	0.12	(-0.23; 0.46)	0.503	-0.26	(-0.61; 0.08)	0.136	0.14	(-0.35; 0.63)	0.586	5.08	(4.85; 5.32)	**<0.001**
Breakfast cereal	1.50	(0.94; 2.06)	**<0.001**	-0.38	(-0.94; 0.19)	0.190	0.16	(-0.64; 0.96)	0.692	0.23	(-0.16; 0.61)	0.248
Eggs	-0.01	(-0.07; 0.06)	0.876	-0.08	(-0.14; -0.01)	**0.019**	0.09	(-0.00; 0.18)	0.051	2.03	(1.98; 2.07)	**<0.001**

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Chapter 5: Exploring the Acceptability, Usability and Likeability of an Artificial Intelligence-Based, Gamified Phone Application Prototype to Track and Improve Food Choices of Adolescent Girls in Vietnam: A Qualitative Study

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Braga, Bianca C.[1], Nguyen, Phuong Hong[2,3], Aberman, Noora-Lisa[4], Doyle, Frank[5], Folson, Gloria[6], Hoang, Nga Thu[7], Hughes, David[5], Huynh, Phuong Nam[7], Koch, Bastien[2], McCloskey, Peter[5], Tran, Lan Mai[8], Gelli, Aulo[2]

[1]Corresponding author: Friedman School of Nutrition at Tufts University. 150 Harrison Ave, Boston, MA, 02111, USA. Phone: +1 617-636-3777. (curi.bianca@tufts.edu)

[2]International Food Policy Research Institute. Eye Street, 1201 I St NW, Washington, DC, 20005, USA (p.h.nguyen@cgiar.org; b.koch@cgiar.org; a.gelli@cgiar.org)

[3]Thai Nguyen University of Pharmacy and Medicine, Thai Nguyen, Vietnam. (p.h.nguyen@cgiar.org)

[4]GAIN Health. 1701 Rhode Island Ave NW, Washington, DC 20036, USA. (naberman@gainhealth.org)

[5]Pennsylvania State University, College of Agricultural Sciences. W115 Millennium Science Complex University Park, PA 16802. (dph14@psu.edu; fdoyl001@gmail.com; pzm44@psu.edu)

[6]Noguchi Memorial Institute for Medical Research in the College of Health Sciences, University of Ghana, Legon, Ghana. (gfolson@noguchi.ug.edu.gh).

[7]National Institute of Nutrition of Vietnam. 48B Tăng Bạt Hổ, Phạm Đình Hổ, Hai Bà Trưng, Hà Nội, Vietnam. (vietnga1124@gmail.com, hnphuong@gmail.com)

[8]Emory University, 201 Dowman Dr, Atlanta, GA 30322, USA. (lan.tran2@emory.edu)

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Abstract

Background

Adolescents' consumption of healthy foods is sub-optimal in low- and middle-income countries. Adolescents' fondness for games and social media, and the increasing access to smartphones make applications suitable to collect dietary data and influence their food choice. Little is known about how adolescents use phones to track and shape food choice.

Objectives

This study examined the acceptability, usability and likeability of a mobile phone application prototype developed to collect dietary data by an artificial intelligence-based image recognition of foods, give feedback and motivate users to make healthier food choices. The findings were then used to improve the design of the application.

Methods

Four focus groups discussions (n=32 girls aged 15-17 years) were conducted in Vietnam. Qualitative data were collected and analyzed by grouping ideas into common themes according to content analysis and ground theory.

Results

Adolescents accepted most individual- and team-based dietary goals presented in the application prototype to help them make healthier food choices. They deemed the overall application wireframes, interface and graphic design as acceptable, likeable and usable, but suggested the following modifications: 1) tailored feedback based on users' medical history, anthropometric characteristics, and fitness goals; 2) new language on dietary goals; 3) provision of information about each of the food group dietary goals; 4) wider camera frame to fit the whole family food tray, as meals are shared in Vietnam; 5) possibility to digitally separate food consumption on shared meals; 6) more appealing graphic design, including unique badge designs to each food group. Participants also liked the application's feedback on food choices in the form of badges, notifications and

statistics. A new version of the application was designed incorporating the adolescent's feedback to improve its acceptability, usability and likeability.

Conclusion

A phone application prototype designed to track food choice and help adolescent girls from low- and middle-income countries make healthier food choices was found to be acceptable, likeable and usable. Further research is needed to examine feasibility of using this technology at scale.

Keywords: adolescent, dietary quality, food choice, gamification, low- and middle-income country, smartphone application

Introduction

Background

The consumption of healthy foods and nutrients is suboptimal worldwide, particularly in low- and middle-income countries. While the daily intake of unhealthy foods (such as red and processed meats, and sugar-sweetened beverages) exceeded the optimal consumption level, the daily intake of healthy foods (such as fruits, vegetables, grains, nuts, seeds, and fiber) is far below the recommended levels globally [1]. The importance of diets rich in fruits, vegetables, and whole grains should not be underestimated [2]. Plant-based diets prevent cancers [3] and cardiovascular diseases [4], and consumption of fruits and vegetables have been associated with increased happiness, life satisfaction, and psychological well-being [5–7]. On the other hand, sugar-sweetened beverage consumption is associated with increased adiposity, long-term weight gain and a higher risk of diabetes [8–11]. The population of Southeast Asia has a low consumption of grains, legumes, fruits, vegetables, nuts, and seeds, and high consumption of processed meat, sugar-sweetened beverage, trans fats, and sodium [1]. Adolescents in this region have especially low consumption of fruits and vegetables [12].

Interventions intended to improve adolescent's knowledge in nutrition and health behavior can take advantage of new technology to self-monitor diets with feedback on performance [13, 14]. Young people are early adopters of mobile phone applications (apps), games and social media, and are highly influenced by peer norms [13, 15, 16]. Mobile phones and computers are now widely used by adolescents from countries of all levels of income [17, 18, 19]. The implementation of nutrition interventions based on apps hold great potential to improve the dietary quality of this population, but its impact is yet to be demonstrated [17].

Prior work

Vietnam is a country in nutrition transition with great changes in food supply, food prices, household expenditure, diet and nutrition outcomes [20]. We previously undertook a review of apps available in the Vietnamese market that could serve as tools for nutrition interventions [18]. The majority of the apps found were focused on tracking and changing food choice with the ultimate goal of losing weight [18]. Food consumption was usually tracked by searching and selecting each food and beverage separately from a dropdown

menu and their portion sizes [18]. This was considered so time consuming that even adolescents from Vietnam interested in changing their diets stopped using these apps [18]. There was a lack of free, user friendly apps that focused on changing dietary quality [18]. We also conducted a literature review for detailed descriptions of electronic- and mobile-health technology used in nutrition interventions [18]. Intervention studies to promote healthy diets in adolescence often ignore techniques to keep subjects engaged, leading to low participation and high drop-offs [18]. Adherence to these interventions is poorly reported in the literature [18].

Research objectives

Our goal is to develop a new app with artificial intelligence (AI) technology to recognize images of foods that can be used to track and influence the quality of food choices of adolescent girls in Vietnam using gamified nudges. Previous apps based on image recognition of foods have been successful in estimating carbohydrate content of meals with higher accuracy than individuals, predicted glycemic dynamics and helped to improve diabetes self-management [21–23]. First, we prepared a food database and an image library by 1) developing a food inventory with priority foods; 2) preparing, cooking and taking graduated pictures of foods; and 3) annotating pictures and linking them to the food database. Second, we used the annotated pictures to train a semantic segmentation model to recognize foods and estimate portion sizes (details of the AI model development are under review elsewhere). Third, we developed the *Food Recognition Assistance and Nudging Insights* (FRANI) app which process included: 1) conducting formative research (two rounds of focus group discussions) with users to develop its interface, and 2) validating the image recognition AI technology against the two gold-standard forms of dietary data collection: 24 hour recalls and weigh food records, and 3) integrating the validated AI technology with the user interface. The app was developed by engineers from our team.

This study is aimed at examining the acceptability, usability and likeability of the FRANI prototype. Our three specific objectives are to obtain qualitative inputs on: 1) the acceptability of its daily individual- and team-based dietary goals to motivate healthier food choices; 2) the usability and likeability of the image capturing feature and the likeability of the feedback to users (badges, notifications and statistics); and 3) to use the

inputs of participants to improve the user interface design and functionality. We hypothesized that FRANI is acceptable, usable and likeable.

Methods

Study design, participants and setting

We conducted two rounds of FGDs with 32 adolescent girls aged 15 to 17 years in Thai Nguyen, Vietnam. The first round of FGDs aimed at developing the FRANI prototype and the second aimed at understanding its acceptability, usability, likeability and make changes so as to improve its dietary goals, camera, and feedback (badges, notifications and statistics). We purposely selected one urban public high school due to having a good relationship with the research team. Twelfth graders were excluded because they were graduating a few months from the recruitment period, which could undermine follow-up studies. Two classes from each of the two remaining grades (10^{th} and 11^{th}) were randomly selected, then eight girls were randomly selected from each of the four classes.

They were approached by the school teachers and divided into four FGDs with eight participants each according to their school year and specialization (social science and language vs. natural and biological sciences). Two of the girls initially selected did not participate because their parents thought the study would take time and interfere with their studies. Two additional adolescents were randomly selected and replaced for those who refused to participate. The randomization lead to a sample of participants that varied in scholastic performance and socio-economic characteristics, described in Table 1. The study design and the reporting of findings were based on content analysis, ground theory and on the Consolidated Criteria for Reporting Qualitative Research (COREQ), which include a 32-item checklist for interviews and FGDs [24].

Research team, data collection and analysis

Two researchers designed a semi-structured questionnaire based on the analysis of the content of themes emerged from previous FGDs [18]. The questionnaire was pilot-tested and changed according to the feedback of the pilot participants. FGDs were then facilitated in Vietnamese by a female senior researcher with a Ph.D. degree and experience with qualitative methods from the National Institute of Nutrition of Vietnam. Two additional female researchers from the Preventive Medicine department of the Thai Nguyen University of Pharmacy and Medicine assisted taking notes, recording the audio

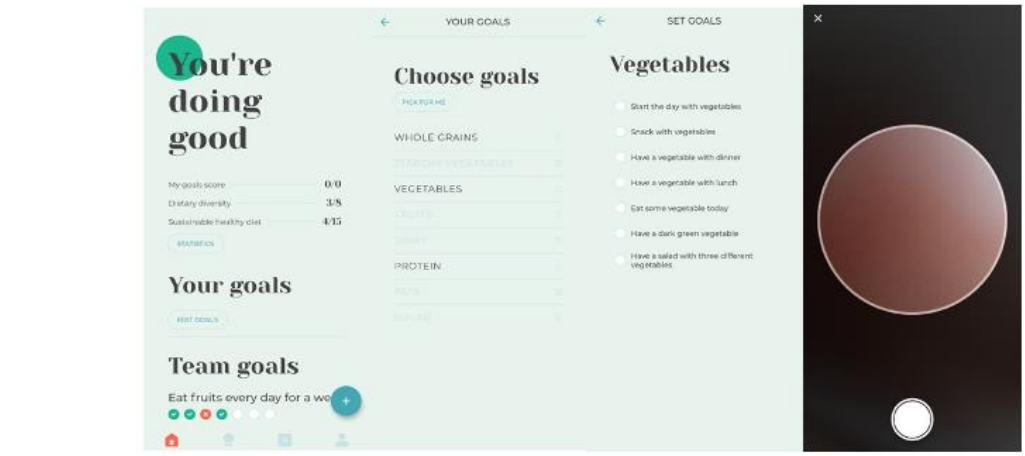
and keeping the time. The researchers did not know the participants prior to the FGDs. Each FGD took approximately two hours and all interviews were completed in November 2020. Another researcher coded the data.

Table 1: Characteristics of focus groups participants (N=32)

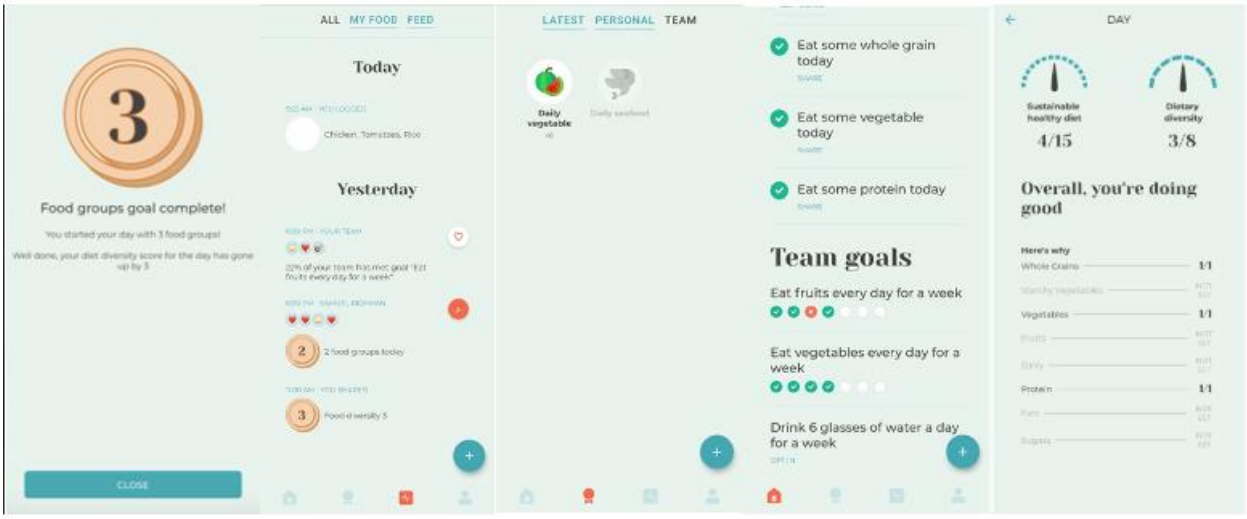
Characteristics of the parents	%	Characteristics of the household and participants	%
Parent's level of education		Household with assets	
Mother		TV	100
Less than high school	25	Computer	69
High school	50	Refrigerator, freezer	100
College	22	Air conditioners	59
Post-Graduate (master's, Ph.D.)	3	Washing machine	88
Father		Gas cooker or stove	100
Less than high school	45	Water heater	91
High school	41	Electric bicycle	59
College	14	Motorcycle	100
Post-Graduate (master's, Ph.D.)	0	Car	28
Parents' occupation		Participants with excellent school performance	
Mother		Math	29
Farmer	16	Physics	32
Blue-collar worker	16	Chemistry	36
White-collar worker	22	Biology	59
Unskilled worker	38	Literature	13
Stay-at-home parent	3	History	55
Other	6	Geography	37
Father		Foreign language	7
Farmer	14	Overall	23
Blue-collar worker	21		
White-collar worker	14		
Unskilled worker	41		
Stay-at-home parent	0		
Other	10		

Excellent school performance is defined as average grades of nine or above out of ten.

The researchers presented the wireframes of the FRANI prototype (Figures 1a-1i) along with short instructions to guide participants to explore its core functionality on their project-provided smartphones. Participants were guided to choose individual-based dietary goals and discussed the acceptability of each of the goal options. These goals for three food groups (vegetables, whole grains and proteins) could be selected from the lists described in Table 2. After selecting goals, participants took and uploaded pictures of foods using the camera tool in the FRANI prototype, and then received feedback from the FRANI prototype. The facilitator asked questions about acceptability, usability and likeability described on Table 3. The FGDs took place in the school participants study.



1a 1b 1c 1d



1e 1f 1g 1h 1i

Figure 1. a-i: Examples of the FRANI prototype wireframes presented for focus groups participants. Fig. 1a home screen, which represents the individual- and team-based scores. The denominators were mistakenly presented in the FGDs as 8 and 15 instead of 10 and 14 signifying the food groups for the DDS and sub-groups for SHDS, respectively. Fig. 1b all food groups for which participants could choose goals during the FGDs. Fig. 1c shows all possible goals for vegetables. Fig. 1d. camera frame. Fig. 1e confirmation screen with a golden badge for completing three goals. Fig. 1f activity screen in which participants can react to what other users posted. Fig. 1g shows team-based badges (faded ones were not achieved). Fig. 1h progress bars for team-based goals (bottom of home screen 1a). Fig. 1i summary of daily statistics. The wireframes presented in the FGDs were written in Vietnamese.

Table 2: List of FRANI individual-based dietary goals that were shown to participants and discussed during the FGDs

Vegetables	Proteins	Whole grains
Start the day with vegetables	Start the day with proteins	Start the day with whole grain
Snack with vegetables	Snack with proteins	Snack with whole grain
Have a vegetable with dinner	Have a protein with dinner	Have a whole grain with dinner
Have a vegetable with lunch	Have a protein with lunch	Have a whole grain with lunch
Eat some vegetables today	Eat some protein today	Eat some whole grain today
Have a dark green vegetable	Vary your protein routine with beans and peas	Try a new whole grain
Have a salad with three different vegetables	Have a protein food with another food group	Have a whole grain with another food group
	Bake, roast, or grill a protein food	

Note: FRANI includes other food groups, but only the ones above were discussed with participants.

All FGDs were tape-recorded and transcribed as non-verbatim. Field notes and interviewers' observations were also incorporated into the transcripts. Transcribed data from the early interviews were reviewed and discussed by the team to identify gaps in data exploration which could be investigated further during subsequent interviews. No new information was generated in the fourth FGD, suggesting theoretical saturation. All transcripts were translated into English and randomly checked by the senior researcher, who is proficient in English and Vietnamese.

Patterns within and across FGDs were reviewed and organized into the most important common themes using NVivo11 software [25]. These themes were: Acceptability of FRANI prototype's individual- and team-based dietary goals; usability and likeability of the FRANI prototype's camera; likeability of the feedback, including badges, notifications and statistics; and the likeability of the graphic design. Transcripts did not return to participants for comments and corrections, and interviews with the same group were not repeated. Each FGD took approximately 2 hours.

Table 3: Questions asked during the focus groups discussions

Acceptability
What do you think about the dietary goals?
What do you think about the process of setting dietary goals?
How does having goals related to food groups help you achieve your personal goals (e.g. getting in shape or being healthier)?
How do you like having team-based goals?
What do you think about the team-based goals?
Would you change or improve the way the team-based goals are presented on the home screen?
On the activity feed, how do you like seeing the combined progress of your team ("22% of your team has met the goal…")?
Do you like how much information can be shared on the activity feed?
How does FRANI compare to other apps you already used to improve your habits in general, and what you eat specifically?
How was FRANI's information relevant for you to understand the basic principles of a healthy diet?
Likeability and usability
How do you like the tool for taking pictures of your meals?
How would you change or improve the design of the confirmation screens (the immediate feedback after taking the photo)?
How do you like the way the feedback on what you ate was provided?
In general, how do you like the idea of receiving feedback each time right after you logged food?
How do you like the idea of receiving medals (badges) each time you reach a goal?
How do you like the design of the medals (badges)?
How do you like the idea of having daily statistics about what you eat?
How do you like the way the three different scores are presented on the statistics screen?
Is the progress bar clear?
Should the layout of that screen be changed/improved?
Do you like using the app? Why?
What features do you like best? Why?
What features do you like least? Why?
What kind of problems do you see with using the app as it's currently designed?
What other features do you miss in this app?
What kind of benefits do you see resulting from using this app?
What kind of problems do you see resulting from using this app?

Note: The three scores used to measure dietary quality and progress on the FRANI prototype are explained in the Appendix 1

Results

Acceptability of the individual-based goals

Acceptability of the vegetable goals

Participants generally considered the FRANI dietary goals listed in Table 3 achievable, and suitable for a variety of people because of the numerous alternatives. Respondents were confident that they could eat vegetables every day, but not in all meals. All alternatives for vegetable goals are illustrated in Figure 1c. The goal 'Eat some vegetables today' was considered easy to achieve, while 'Eat vegetable for a snack' and

‘Start the day with vegetables’ were considered hard to achieve. ‘Have a salad with three different types of vegetables’ was seen as part of a “Western diet”, unsuited for the Vietnamese culture, because they understood a salad to be exclusively composed of leafy greens. When informed that root vegetables could be part of the salad group, they suggested the goal to have two vegetables, because three was an uncommonly high variety of vegetables for one meal. A group of participants suggested changing the goal ‘Have a salad with three different types of vegetables’ for ‘eat *nộm*’, meaning “a mix of vegetables” in a local dialect, although the term may not be understood in other regions of Vietnam. The goal of ‘Having a dark green vegetable’ was seen as meaningless because they did not comprehend how the color of food could impact nutrition and had difficulty distinguishing dark green from light green vegetables. There were also concerns about exposure to pesticide residue on vegetables.

Acceptability of the protein goals

Respondents were unclear about what constitutes a plant-based protein. The facilitators explained that the objective of the ‘Vary your protein routine with beans and peas’ goal was to facilitate the replacement of animal proteins with plant protein – for example, with soybeans, peas, or tofu. Some participants held that FRANI should show examples of plant-based proteins to facilitate comprehension; others suggested changing the guidance to ‘Eat plant-based proteins instead of animal-based protein’. This goal and ‘Snack with protein’ were seen as hard to achieve, because adolescents mostly eat pastries, cake, or candies as snacks. The healthfulness of the cooking methods of the goal ‘Bake, roast or grill protein-rich foods’ divided opinions. Some asked to include an explanation in FRANI about why proteins should be roasted, grilled, or baked. Others proposed boiling, air frying, and steaming, noting that well-known health influencers used these methods of cooking.

Acceptability of the whole-grain goals

Whole grains, which include rice, wheat, corn, and others [26], were widely mistaken for packaged breakfast cereals. *“I thought that [whole grain] was a packaged cereal.”* [FGD 1]. Others thought whole grains were a synonym of unprocessed food or snacks: *“I think that whole grains are foods that have not undergone many preparations and are pre-processed."* [FGD 3]; *“[A whole grain] is everything that is considered a*

snack, for example, bread, or milk" [FGD 1]. Most whole-grain goals were seen as either achievable or redundant after leads explained their meaning. The only exception was the goal 'Start the day with a whole grain', which was perceived as difficult to achieve for those who did not eat breakfast. Participants thought that the goal 'Try a new whole grain every day' required too much cooking time and creativity. To avoid misunderstanding, it was suggested that 'whole grains' should be renamed.

The relationship between the dietary, health and fitness goals

Overall, participants were interested in healthy eating but felt rightly unequipped to make healthy food choices for themselves. All participants said FRANI should ask for weight and height, medical history, and fitness and health goals. Based on this information, it should suggest personalized, suitable dietary goals that consider both the quality and quantity of food groups. *"There must be a complete set of information. It [FRANI] cannot help us with anything if it's too vague. When people have filled out all the information [weight, height, medical history, and health condition], the app should make personalized suggestions so people can pay attention to what they eat"* [FGD 3].

Most participants would only use an app that could help them achieve fitness goals, so there was high demand for a feature to set goals such as weight gain or loss and building muscle mass. They said FRANI should suggest what dietary goal users should set to achieve their health and fitness goals, and indicate what and how many foods groups, nutrients and calories were missing from each meal. *"The app's purpose is to promote healthy eating, (...) but I still don't know [after choosing dietary goals on FRANI] if the way I eat is right or wrong, if it's nutritionally inappropriate... The app has to give me advice so I can follow it"* [FGD 3]. *"Choosing goals should not be based on 'users' opinions'"* [FGD 4]. Other comments suggested difficulty deciding between multiple goals and some said FRANI should choose the dietary goals for them. Also, they said FRANI should provide information about what foods are contained within each food group to avoid misunderstandings. FRANI was interpreted as an app better suited for helping with weight gain than weight loss because receiving rewards for achieving multiple goals was associated with eating more.

Acceptability of the team-based dietary goals and competition

The team-based goals included "eat fruit", "eat vegetables" and "drink six glasses of water". At the bottom of the home screen, there was a progress bar for active goals with one box for each day of the week (Figure 1h). Individual members of a team would have their box checked if they met the goal that day. For example, if a user chose to opt-in to a team-based goal of having fruits every day, they would be grouped with other users who opted-in to the same goal. If the individual user achieved that team goal for that day she would have the box checked, turning it green, or leave it red if she did not. Participants liked the idea of competing in teams. Some suggested adding a search engine to find users by their names, invite contacts to join FRANI, and receive friendship suggestions so that they could have friends as teammates.

Some were more excited about team- than individual-based goals, saying that competition could trigger motivation, create connections, and foster social support. They wanted more options for team-based goals because the team-based goals available were seen as easy to achieve. *"The team-based goals are easy to achieve because these are foods that we eat every day and that are essential"* [FGD 1]. They would like to see team members individually ranked, with the lowest achievers at the bottom and the highest achievers at the top. *"Here [home screen] it must have a specific team name, and when I click on the team name, I see what goals people have achieved today and the rankings of the team members below."* [FGD 3]. Many claimed that underachievement would make them try harder and they were not worried with peer pressure.

Usability and likeability of the image capture camera

Many participants said that families would support the use of FRANI as long as it helps to improve the quality of their diet. However, several challenges were raised. The first perceived usability barrier of the FRANI was the size of the FRANI camera window, considered too small to capture images of whole family food trays (Figure 1d), since meals are typically served and eaten communally in Vietnam. Another perceived barrier to usability was the inconvenience for family members to wait for the process of taking pictures complete before starting to eat their meals. Furthermore, separating what they eat from the rest of the family meal would be seen as disrespectful for most families, especially in the presence of older adults, house guests, and in restaurants. "*If there are many people*

of my family [during mealtime], including the elders, it would be strange for me to separate my food from everyone else." [FGD 3].

An additional usability limitation was that participants did not know how much they ate during shared family meals. "*When eating with others, we share food so it [food consumption attributed by FRANI to user] can't be accurate. It's complicated when many people are eating at once."* [FGD 3]. Relatedly, after taking and uploading photos, they may consume additional servings. Thus, participants requested a wider camera frame as well as a feature to digitally separate what users ate.

Finally, participants were concerned about how much the picture could illustrate the food. *"There are many things in a sandwich, but the app won't know all the ingredients unless I take it apart"* [FGD 2]. They also talked about the difficulty of taking pictures from foods that come inside of packages, such as potato chips. They suggested FRANI to recognize food packages. They also wanted the ability to upload food pictures to the app after meals to avoid the inconvenience of waiting for other family members, or in case there was no internet access. They would prefer to be able to log the same picture for multiple similar meals, to save time and phone memory.

Likeability of the feedback, including notifications, badges and statistics

Participants said they would like FRANI to give immediate feedback on the quantity and quality of foods eaten, including indication on which foods are unhealthy so to help them make healthier choices for their next meal. *"It [FRANI] should provide an immediate response so that I can learn from the previous experience for the next meal."* [FGD 4]. Some said they would rather receive a brief notification reminding what they still have to eat to achieve individual-based dietary goals then to get a daily report at night with the summary of what was eaten. They said FRANI should also notify users about dietary goals that were not met at the end of each day, and remind them to take pictures at the time of their meals. Others would like to choose the time of the day to receive notifications.

Badges, or visual representations of individual- and team-based dietary goals achievements (Figures 1e), are a form of feedback that can be shared with FRANI friends on the activity screen (Figure 1f). The badge system ranges from bronze to silver to gold, and streak badges praise for high dietary diversity multiple days in a row. They liked the badge system, but preferred to receive one badge a day only. *"I think there should only be*

one badge a day. This means that if you accomplished all three goals very well, you'll get a gold badge, if you did not do too well (…) you would get a silver badge. If you didn't accomplish any goals, you will not get a badge." [FGD 3]. Participants liked that friends could react (send "hearts") when they shared their badges in the feed and agreed that comments should not be allowed to avoid cyberbullying (Figure 1f).

Participants were also presented with statistics of food intake with simple charts designed to minimize cognitive load [27]. Most understood the three different dietary scores calculated by the FRANI prototype, explained in the Appendix 1. Participants liked the daily statistics about the dietary scores for individual goals (Figure 1i). They suggested the diagrams to show if users met goals, including how much was eaten from each food and how much they would still need to eat to achieve the goals. They would like to have their history of daily statistics permanently saved on FRANI.

Likeability of the graphic design

Participants wanted FRANI prototype's graphic design to be more colorful and icons to be brighter. The graphic design of the badges was considered unattractive (Figures 1e and 1g). Any food logged by participants during the FGDs showed a watermelon icon as a badge (Figure 1g), so they thought the FRANI prototype was not recognizing the foods correctly. This was not a recognition mistake, but an unclear graphic design. They suggested that each food should have its own differentiated badge. They also said the graphic design should be more intuitive. The plus ('+') icon to take pictures on the home screen (Figure 1a) should be replaced by a camera icon.

Discussion

This formative research investigated the acceptability, usability and likeability of an AI-based, gamified mobile phone app prototype to track and improve the nutritional quality of food choices of adolescents girls in Vietnam. The FRANI prototype was designed to self-monitor and influence food choices considering the capabilities of and opportunities for potential users [28]. We included game elements, such as setting dietary goals and giving feedback on performance that included a badge system, notifications and statistics, to motivate the app use [29-33]. We also added elements of social media such as sharing information with other users, a newsfeed and possibility to react positively to what

others posted [32]. Participants of four FGD provided feedback on the app prototype, informing platform designers about their expectations [34].

Acceptability of the individual-based goals

Most participants had previously tried using various nutrition and health apps to track physical activity, diet, and health in general. Yet, they deleted these apps within a few weeks after downloading, due to excessive battery consumption (i.e. for counting steps) and time spent to complete required tasks (i.e. for logging food consumption). Adolescents preferred apps focused on behavior change that would help them achieve immediate, potentially unhealthy fitness goals (i.e. losing weight quickly) rather than focusing on health benefits (i.e. improving dietary diversity). This is in line with the idea of *young invincibles* described in the literature: adolescents tend to make unhealthy food choices due to their low likelihood of developing diseases at their life stage [35]. FRANI was carefully designed to not reinforce this tendency. We opted to inspire continued use of the app by reinforcing the comprehension of the goals [32] and by increasing the saliency of healthy food choices.

Participants accepted most FRANI dietary goals related to vegetable, protein and whole-grain consumption. The dietary goals that were not understood had their language changed in the updated version of FRANI (Appendix 2a-2j). Some participants would prefer FRANI to assign them goals based on medical history and anthropometric characteristics, instead of choosing dietary goals themselves. This is because they rightly did not feel knowledgeable enough about nutrition to make choices that would optimize health and fitness. Despite their lack of confidence to set appropriate dietary goals, FRANI was designed with the expectation that achieving the goals set would improve dietary quality as long as the dietary goals are changed daily and goals are achieved [18]. Furthermore, the advantages of fostering habit formation by setting specific goals [36] could be undermined by automatizing this process. As such, the updated version of FRANI does not suggest dietary goals for users. This was an example of incongruency between what users said they wanted and research objectives and theory -- a problem that has been previously described in the literature [37].

Following participants' suggestions, the updated version of FRANI's image recognition software estimates the weight of foods and beverages and gives feedback on

quantities (Figure 2f). Goal setting, however, was maintained as purely qualitative because maintaining simplicity may be important to the user's experience. The updated version of FRANI also includes information pages with infographics, detailed explanations for food groups, goals, scores, and health implications of achieving goals. The incorporation of user goals and expectations should lead to higher motivation to use this technology, and more effective future digital interventions [38, 39].

Acceptability of team-based dietary goals and competition

Team-based challenges were widely accepted as they were seen as means for self-improvement driven by competition. Participants suggested a form of within-team competition: FRANI should show individual achievement information for all team members and rank them accordingly. However, the updated version does not do that because we want avoid excessive peer pressure, given that changes in the brain and increased testosterone during this life stage have been associated to a more sensitivity to social evaluation and influence [40].

Usability and likeability of the camera

The updated version of FRANI has a wider camera frame that fits whole family food tray, and has a function to digitally separate the food portions eaten by users from the rest of the family meal (Figure 2d). Concerning the difficulty of capturing the multiple ingredients of foods (for example, a sandwich) and foods inside of packages, FRANI now also recognizes images of packages, and it is possible to manually log the ingredients that were not captured by the AI technology from the picture. The manual log in of ingredients is more time consuming than taking pictures of foods, but also increases the overall accuracy of the app.

Likeability of the feedback, including notifications, badges and statistics

FRANI gives personally-relevant feedback using credible nutrition information in the form of notifications, badges and statistics. Participants demonstrated extensive interest in receiving personalized feedback from FRANI, which is important to keep users motivated and engaged [38, 41], and it works better than *one size fits all* feedback [39, 42]. Receiving feedback has been shown to have the potential to break undesired habits [43, 44]. However, some adolescents wanted to receive negative feedback when recording unhealthy foods.

In accordance with the desire of participants, the updated version of FRANI sends *just-in-time* notifications reminding users to take pictures at breakfast and lunchtime, which can lead to behavior change [45-47] and habit formation [48]. Notifications now can be turned on and off, but it is not possible yet to choose the time of the day and length of the notifications received. We chose to not send feedback disapproving unhealthy food choices, nor suggesting substitution for healthy foods because it can be counterproductive and encourage unhealthy food consumption [49]. Adolescents are also particularly prone to eating disorders [50, 51], so we tried to minimize the stress that negative feedback could generate.

Study participants saw badges as an effective way to support behavior change, but the effects of badges, although promising, have not yet been teased out from other incentives in the nutrition behavior literature [29]. Using badges as rewards can be effective to encourage positive responses, such as supporting desirable studying practices [31], increasing participation and engagement in schooling [52], supporting professional development [53], and stimulating voluntary contribution in online communities [54], among others. Participants were interested in self-monitoring through daily statistics, and suggested that FRANI should save historical dietary data. The updated version of FRANI will displays dietary records.

Likeability of the graphic design

In line with the ground theory, participants showed a preference for a simple interface with an appealing design [18, 55-57]. The extent of the engagement benefits of electronic- and mobile-health depend on appropriate design, that should be persuasive and personally relevant [58]. The updated interface is simple and more visually appealing. The badges sent to praise achievements related to any food group during the FGDs had a watermelon design, which was confusing to participants. The updated version of FRANI has badges with distinctive designs for accomplishments based on each food group (Appendix 3).

Strengths and limitations

The main strength of this study is the in-depth qualitative assessment of the FRANI prototype. Although this assessment was based on the presentation of the prototype during the focus groups discussions and not on real user experience, the process we herein

describe can help other researchers to build acceptable, usable and likeable tools for interventions. This may increase the participation and adherence in future studies. Because our study has small sample size from a limited geographical location, findings cannot be generalized to other countries, cultures, genders, and age groups.

Conclusion

Participants accepted FRANI and deemed it usable and likeable conditionally on the following modifications: 1) tailored feedback based on users' medical history, anthropometric characteristics, and fitness goals; 2) new language on dietary goals; 3) provision of information about each of the food group dietary goals; 4) wider camera frame to fit the whole family food tray, as meals are shared in Vietnam; 5) possibility to digitally separate food consumption on shared meals; 6) more appealing graphic design, including unique badge designs to each food group.

The findings on the FGDs served as a guide to improve the FRANI prototype that may also help other researchers design tools for different interventions. The acceptability, usability, and likeability of the new version of FRANI, along with an assessment on the effects of using FRANI to improve food choices and dietary quality will be quantitatively examined in a randomized controlled pilot study. As far as we know, FRANI is the first AI-based, gamified self-monitoring app focused on improving the diets of adolescents in low- and middle- income countries. If successful, this tool will help to improve female adolescents' diets, and will make high-frequency data collection on food consumption possible, minimizing errors, decreasing long-term research costs and helping to fill the gap of adolescent's food consumption data collection [59].

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Ethical statement

Methods and materials for the FGDs were approved by the Institutional Review Boards of the International Food Policy Research Institute (protocol code #00007490) and the Thai Nguyen National Hospital (protocol code 274/ĐĐĐ-BVTWTN). All participants

assented to participate, and their parents consented to their participation. Participants were paid 50,000 Vietnamese Dongs. All procedures were in accordance with the Declaration of Helsinki.

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AG, BCB, and NA designed the study. AG, AK, BCB, BK, DH and PM provided inputs in the wireframe design and prototype of FRANI. FD programmed the prototype. AG, BCB and BK wrote the FGD scripts. BCB and BK designed the discussion guide. GF designed the codebook. PHN, LMT, NTH, PNH recruited the participants and ran the FGDs. BCB coded and analyzed the FGD transcripts. BCB wrote the manuscript. PNH, NA, BK and AG revised the manuscript. All authors read and approved the final version of the article. We thank Alexei Stulikov and Rohit Gangupantulu for the support on the design of the prototype. The sponsors were not involved in the study design, nor in the collection, analysis and interpretation of data, nor on the writing of the report and its submission to publication.

Conflict of interest

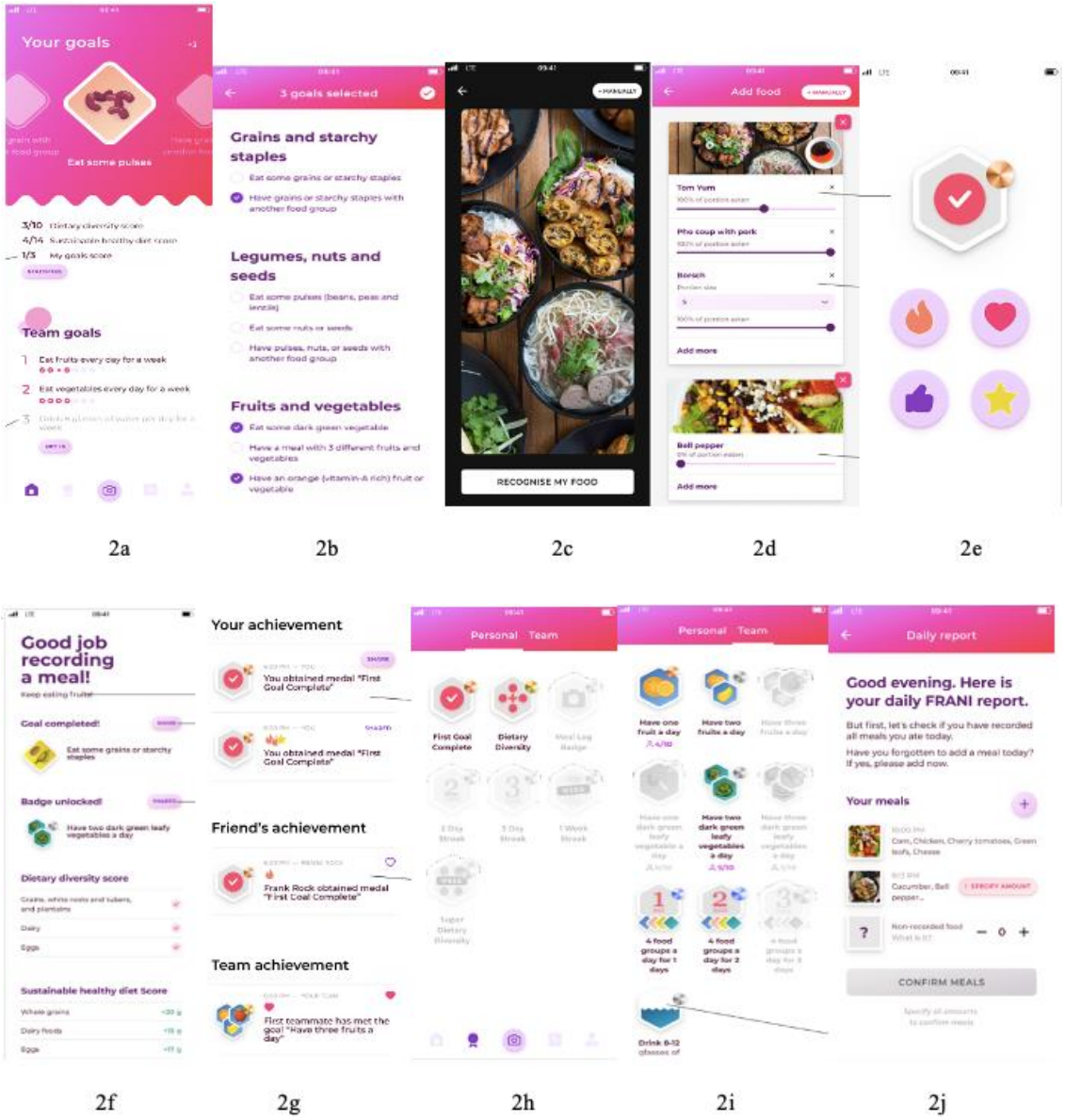
Authors do not have conflict of interest.

Data Statement

Data is available upon request to the authors. A formal data sharing agreement is needed. The lead author has full access to the data reported in the manuscript.

Appendix 1: FRANI dietary scores

FRANI uses three different scores to evaluate the healthiness of diets, the Dietary Diversity Score (DDS), the Sustainable Healthy Diet Score (SHDS), and the My Goals Score. The DDS uses a 10-food group classification from an existing indicator—the Minimum Dietary Diversity for Women (MDD-W) [60], and calculates a score based on the sum of all distinct food groups in the participants' diets each day. The 10 food groups are grains, white roots, and tubers and plantains; pulses (beans, peas, and lentils); nuts and seeds; dairy; meet, poultry and fish; eggs; dark green vegetables; other vitamin A-rich fruits and vegetables; other vegetables; and other fruits. The SHDS counts the number of food sub-groups which consumption stayed within a desirable quantity range from the EAT-Lancet diet report. The EAT-Lancet Diet tries to balance nutrition with environmental concerns [26, 61]. The score ranges from zero to 14 per day based on 14 food sub-groups: rice, wheat, corn and other; potatoes and cassava; all vegetables; all fruits; whole milk or derivative equivalents; beef, lamb, pork; chicken, other poultry; eggs; fish; dry beans, lentils, peas; soy foods; peanuts or tree nuts; palm oil, unsaturated oils, dairy fats (including milk), lard or tallow; and all sweeteners. whole grains, tubers, and starchy vegetables, vegetables, fruits, dairy, protein sources, legumes, added fats, and added sugars. Perfect scores for the DDS and the SHDS would be given for those who eat all food groups of DDS and stayed within the desirable quantity range of all sub-groups of the SHDS on a given day. The My Goal score is the proportion of food groups eaten from the food groups chosen by FRANI users as their personal dietary goals for a given day. FRANI has three dietary quality scores to allow users to explore different aspects of diets that are complementary to each other.



Appendix 2a-2j: Examples of FRANI wireframes after changes based on feedback from the focus groups participants. Fig. 2a home screen, which represents the individual- and team-based scores with brighter colors and the right denominators for the DDS and SHDS. Fig. 2b shows three of the food groups for which users will be able to choose goals (they can also choose goals for dairy and meat when scrolling down). Fig. 2c wider camera frame. Fig. 2d slide bars to digitally indicate how much users ate from foods recognized. Fig. 2e shows the confirmation screen with a bronze badge. Fig. 2f summarizes completed goals, badges, and quantities. Fig. 2g activity screen. Fig. 2h individual-based badges. Fig. 2i team-based badges with one design for each type of food. Fig. 2j FRANI daily report sent at night for users so they can include, complete or correct information uploaded throughout the day. There will be English and Vietnamese options for FRANI.

Appendix 3: Design of new badges based on remarks from the focus groups discussions. Colors are brighter than in previous badge versions, food groups have different badges, and users are levelled up from bronze to silver to gold depending on what they achieved.

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Chapter 6: Feasibility of an artificial intelligence-based phone application and randomized pilot study to improve the quality of food choices of female adolescents in Vietnam

Bianca C. Braga[1*], Phuong H. Nguyen[2,3], Lan Mai Tran[4], Nga Thu Hoang[5], Alejandra Arrieta[2,6], Boateng Bannerman[7], Frank Doyle[8], Gloria Folson[7], Rohit Gangupantulu[8], Naureen Karachiwalla[2], Bastien Koch[2], Peter McCloskey[8], Giordano Palloni[2], Trang Huyen Tran[3], Duong Thuy Trương[3], David Hughes[8], Aulo Gelli[2].

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[1]*Corresponding author. Friedman School of Nutrition Policy and Science, Tufts University, USA. 150 Harrison Ave, Boston, MA 02111, United States. Telephone: (617) 636-3777. Curi.bianca@tufts.edu.

[2] Poverty, Health and Nutrition Division, International Food Policy Research Institute, USA

[3]Thai Nguyen University of Pharmacy and Medicine, Vietnam

[4] Hubert Department of Global Health, Rollins School of Public Health, Emory University, USA

[5]National Institute of Nutrition, Vietnam

[6]School of Public Health, University of Washington, USA

[7] Noguchi Memorial Institute for Medical Research, College of Health Sciences, University of Ghana, Legon, Ghana

[8]College of Agricultural Sciences, Pennsylvania State University, USA

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List of abbreviations:

ELDS: Eat-Lancet Diet Score

FRANI: Food Recognition and Nudging Insights

GDQS: Global Diet Quality Score

LMIC: Low- and middle-income countries

MDDW: Minimum Dietary Diversity for Women

Abstract

Background: Malnutrition in adolescence have faced a pervasive policy neglect, partly due to the gaps in dietary intake data for this age group. The Food Recognition Assistance and Nudging Insights (FRANI) is a smartphone application validated for dietary assessment designed to influence users' food choices.

Objectives: Assessing the feasibility (adherence, acceptability and usability) of FRANI and its effects on dietary quality.

Methods: Female adolescents (n=36) were randomly selected from a public school in Vietnam and allocated into two groups. The control group received smartphones with a version of FRANI limited to dietary assessment, while the intervention received phones with gamified FRANI. After the first four weeks, both groups used gamified FRANI for further 2 weeks. The primary outcome of the study was the feasibility of using FRANI as measured by adherence, acceptability and usability. Adherence was the proportion of completed dietary recalls. Acceptability and usability were the proportion of participants who considered FRANI acceptable and usable according to answers of a questionnaire about likeability, satisfaction, intent to use and continue using the app. Secondary outcomes included the percentage of meals recorded, the Minimum Dietary Diversity for Women (MDDW) and the Eat-Lancet Diet Score (ELDS). Poisson regression models were used to estimate the effect of FRANI on the MDDW and ELDS.

Results: Adherence to the app was 81.7% and the percentage of meals recorded was 97%. FRANI was considered acceptable and usable by 35 of 36 adolescents (97.2%). MDDW in the intervention group during the pilot period was 1.07 points [CI 95% (0.98; 1.18); p=0.13] greater than that in the control (constant=4.68), though the difference was not statistically significant; and ELDS in the intervention was 1.09 [CI 95% (1.01;1.18); p=0.03] points greater than in the control (constant=3.67).

Conclusions: FRANI was feasible and may be effective to influence users towards healthy food choices. Further research is needed on the impacts of FRANI in different contexts and at scale.

Keywords: Adolescence, dietary assessment, dietary intake, dietary quality, feasibility, randomized controlled trial, artificial intelligence, phone application, e-health, m-health.

1. Introduction

Technology-based dietary assessment is rapidly growing with the sheer number of people who own cell phones and use phone applications (apps) (Rangan et al., 2016). The automation and standardization of real-time food consumption data collection and coding with mobile phones have great potential to reduce research burden and cost (Sharp & Allman-Farinelli, 2014). Researchers and participants are more inclined towards electronic than conventional dietary assessment methods for the precision and time saved (Carter et al., 2013; Rollo et al., 2011). Real-time data can be used to detect and address adherence issues and procedural problems early on, while real-time communication can be used to request information from participants, fix incorrect entries, and give personalized dietary advice in intervention studies (Sharp & Allman-Farinelli, 2014). Despite advantages, electronic-based food records are often employed in dietary surveys and interventions without prior validity and usability tests (Rangan et al., 2016).

The Food Recognition Assistance and Nudging Insights (FRANI) is an app validated for dietary assessment in Vietnam (Braga et al., 2021; Nguyen et al., 2022). This novel form of data collection uses artificial intelligence technology to recognize foods in photos recorded by study participants and integrates this with the Vietnamese food composition database from the Food and Agricultural Organization (FAO, n.d.). FRANI performs as well as 24-hour recalls and weight food records for energy, macronutrient and micronutrient intake of female adolescents (Nguyen et al., 2022). The overlook of adolescent nutrition in research and policy worldwide has led to large gaps in data collection of food consumption for this age group (Hargreaves et al., 2022; Patton et al., 2016). FRANI also has the potential to be an intervention tool to improve dietary quality, but feasibility and impact have not been tested yet.

To test feasibility and impact, we gamified FRANI's interface according to feedback on wireframes from focus groups discussions with female adolescents from Vietnam (Braga et al., 2021; Braga et al., 2022). Gamification applied to nutrition is the use of game elements such as point scores, badges, progress bars, leaderboards, performance graphs or avatars in interventions to promote healthy eating (Ezezika et al., 2018; Maher et al., 2014). The game mechanisms uses social influence and interaction, that have power to change health behavior (Laranjo et al., 2014). Individuals use

observations about how others behave as a guide to appropriate behavior (Bort-Roig et al., 2014). There are still few publications aimed at measuring the impact of game elements in nutrition behavior, but evidence suggests it is an increasingly used valid and effective strategy (Baranowski et al., 2019; Azevedo et al., 2019). Gamification has encouraged fruits and vegetables consumption (Yoshida-Montezuma et al., 2020), has helped to improve nutrition knowledge (Azevedo et al., 2019; Suleiman-Martos, 2021) and to change the nutrition quality of food purchases in online grocery shopping (Braga et al., under review). Adolescence is a pivotal period to form eating habits (Spear, 2002; Diethelm et al., 2012); and the dietary patterns that emerge have long-term consequences for the development of chronic illnesses in adulthood (Cunha et al., 2018; Dahm et al., 2016). This study assesses FRANI's feasibility (adherence, acceptability and usability) and the potential of its gamified version to improve the dietary quality of female adolescents in Vietnam.

2. Methods

Study design and participants

This study had two parts: 1) a randomized controlled pilot, conducted in the first 4 weeks, and 2) a feasibility study, conducted in the last two weeks (Figure 1). Thirty-six adolescent girls aged from 12 to 18 years were randomly selected to participate from a public school in Thai Nguyen, a secondary city in Vietnam. The school was chosen based on proximity and existing relationships with the research team at the Thai Nguyen National Hospital. Prior to the pilot study start, participants were randomly allocated into intervention and control groups. Participants in the control group received phones with a version of FRANI with functionality limited to dietary assessment (herein referred to as limited FRANI). The intervention group received phones with a gamified FRANI interface. Participants in both groups were separately trained by the research team on how to record food consumption on FRANI (Figure 2). A two-day troubleshooting period followed, when participants practiced using FRANI to record food consumption and problems related to app use were resolved. On day four, participants in both groups were free to use FRANI for the following four weeks. Upon completion of the randomized pilot period, the feasibility study started in the fifth week. The participants in the control

group had limited FRANI erased from their phones and gamified FRANI downloaded by the research team. This was to double the number of participants that could answer Likert questions on acceptability and usability and measure adherence based on the gamified version of the app.

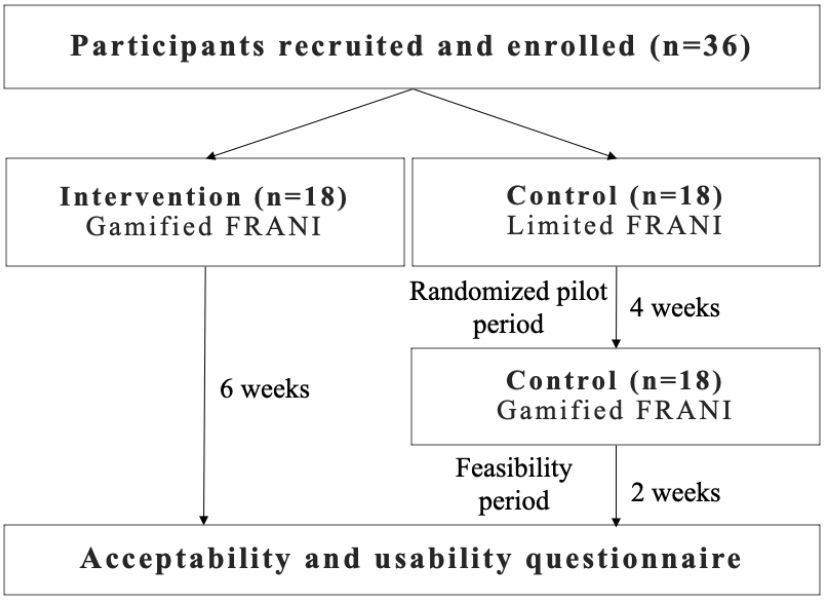


Figure 1: CONSORT diagram. All participants recruited to the study were enrolled.

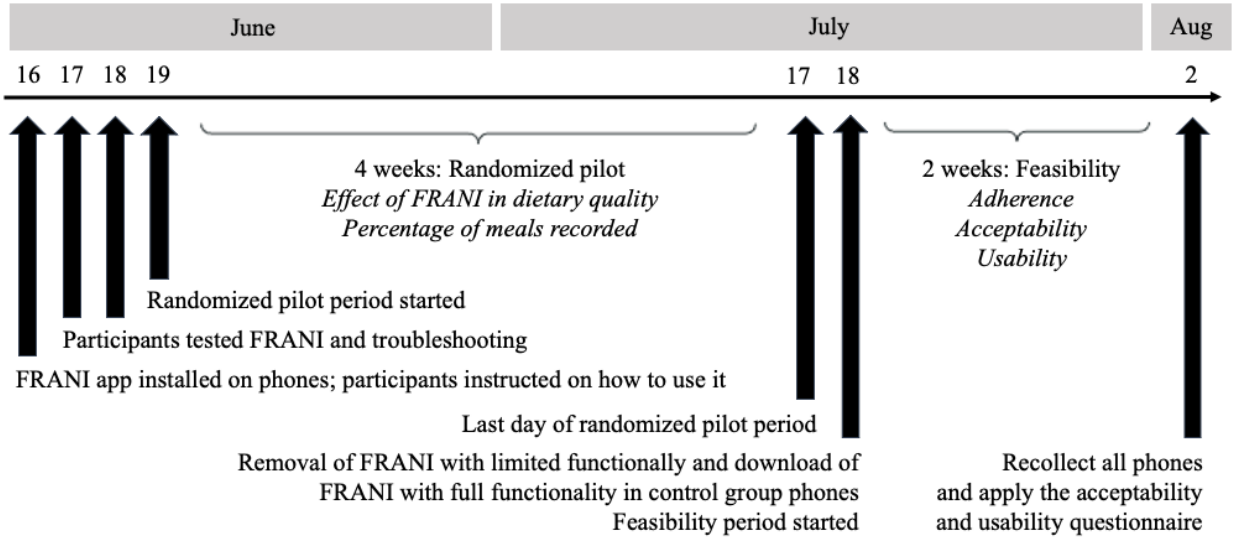


Figure 2: Timeline of the randomized pilot and feasibility study.

FRANI functionality description

Qualitative research undertaken as part of this project found that female adolescents from Vietnam had previously tried to track food consumption using

commercial apps, but stopped because they were difficult to use and time intensive. Uploading food consumption information involved a multi-step process that included finding each food or ingredient separately on a dropdown menu and guessing their weight (Braga et al., 2022). Adolescents believed their diet was unhealthy, but did not trust the nutrition advice from those apps and followed fad diets (Braga et al., 2021; Braga et al., 2022); commercial apps might evoke unhealthy behavior (Gan & Allman-Farinelli, 2011). Recent findings suggest that effective strategies to improve adolescent health must be multifaceted and adapted to local context (Hargreaves et al., 2022). FRANI was designed to be a practical dietary assessment tool and promote healthy eating based on the behavioral scientific literature and the food-based Dietary Guidelines of Vietnam (Braga et al., 2021; Braga et al., 2022; FAO, n.d.).

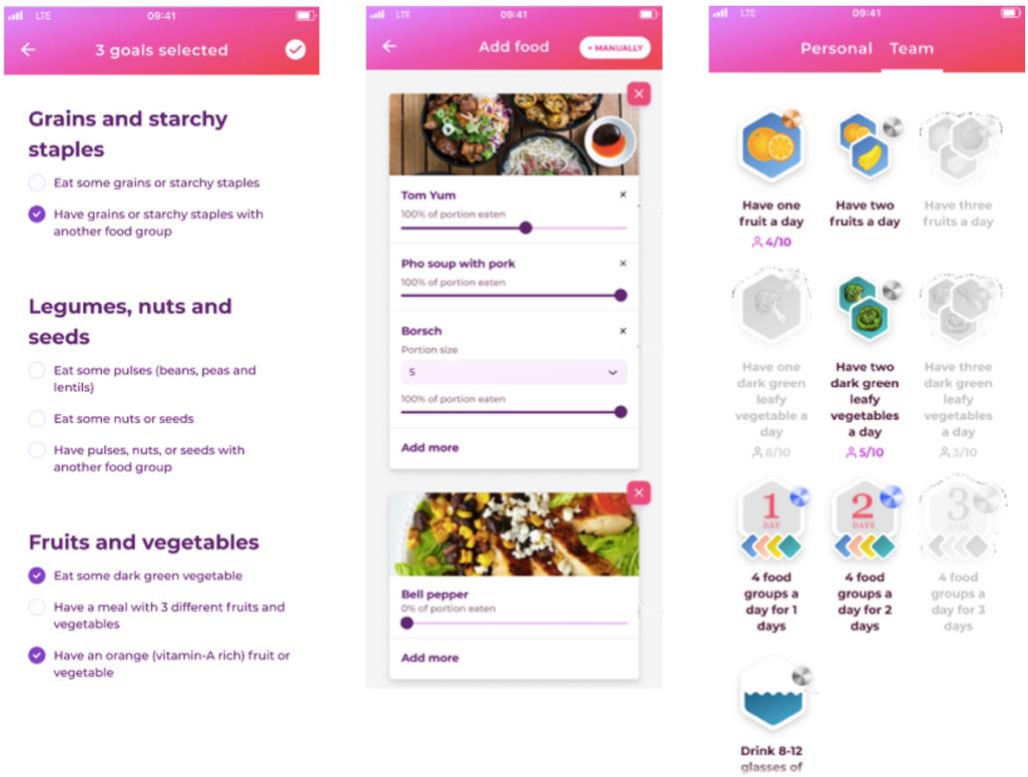
Difference between the gamified and limited FRANI versions

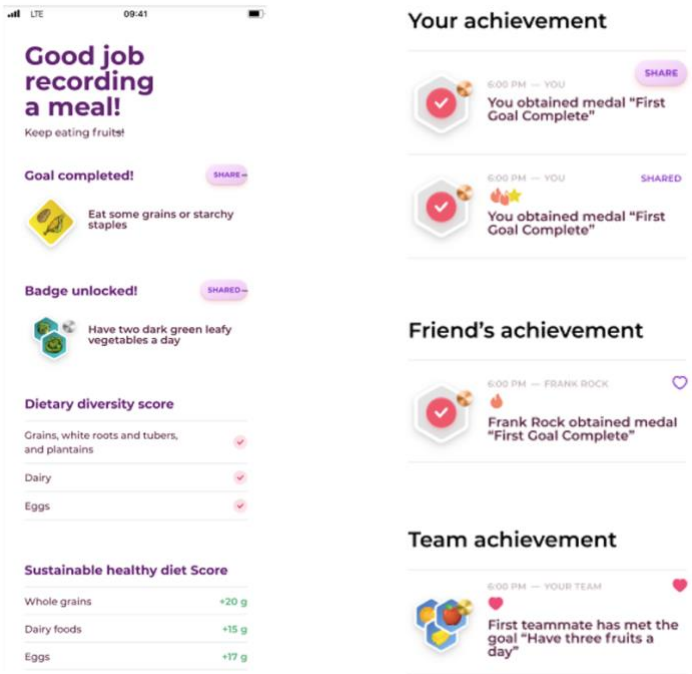
Account registration and login, notifications to remind participants to record meals and meal recording were similar in the gamified and limited FRANI versions. The word "meals" means both meals and snacks in this study, but FRANI had a more comprehensive term in Vietnamese to communicate the concepts of meals and snacks for the participants. Meals could be recorded manually, by taking photos or a combination of both; the information was automatically saved. Taking pictures to record meals was more practical and time saving than manual entry. But if a whole meal or part of it was not recognized from a picture by FRANI, the participant could input the information manually by looking for the food in a drop down menu. Only participants using the gamified version could set food consumption goals, that were point scored and summarized in the statistics page daily and over the latest seven-day period. Both groups received a final prompt every evening to include foods consumed that had not been logged yet to avoid incomplete dietary recalls; and also include the number of meals that had not been recorded to classify that recall as complete or incomplete. Only the gamified FRANI sent daily reports in the evenings summarizing food consumption. The differences between the gamified and limited versions are summarized in the Appendix 1.

Gamified FRANI prompts to change behavior

The gamified FRANI automatically tracked progress against food-group goals and awarded badges as incentives for achieving individual- or team-based goals.

Participants could join teams for one week to have shared goals with other team members. For example, if the team-based goal was to eat one fruit every day, the team members would be rewarded with a badge in case all of them consumed fruits that day. Participants could share their badge achievements in the activity screen and receive positive feedback (hearts) from FRANI friends, as in social media. Social media use is in rapid rise in low- and middle-income countries (Ortiz-Ospine, 2019; Poushter et al., 2018). Each food group had its own badge design, and participants were levelled up from bronze to silver to gold depending on how many days on a row they achieved dietary goals. The gamified FRANI also has badges for dietary diversity. The alternatives for food consumption goals were based on the food groups of the United States Depart of Agriculture's My Plate app (USDA, 2022) and adapted to the Vietnamese context according to the food-based dietary guideline of Vietnam and information from previous focus groups discussions (Braga et al., 2021; FAO, n.d.). Figure 3 shows examples of the gamified FRANI wireframes translated to English. Appendix 2 has more examples of wireframes.





Figures 3: From left to right, top to bottom, wireframe one shows options of food consumption goals for three of the five food groups (in addition to dairy and meat). Wireframe two shows the slide bars to indicate the proportion consumed of the meal recorded, wireframe three shows badges. Wireframe four is the home dashboard and five is the activity screen, where users can share achievements with friends, that can react to it by clicking in the hearts. Participants used FRANI in Vietnamese.

Outcome measures

The secondary outcomes of the study were the percentage of meals recorded, and dietary quality in the first four weeks of the study. The percentage of meals recorded was the number of meals recorded divided by the number of meals consumed. FRANI asked participants to self-report at the end of each day the number of meals they did not record throughout that day. Dietary quality was measured based on the Minimum Dietary Diversity for Women (MDDW) (Arimond et al., 2010; WDDP Study Group, 2017) and the Eat-Lancet Diet Score (ELDS) food groups (Knuppel et al., 2019; Willet et al., 2019). For ease of interpretation of participants, these indicators were named the Dietary Diversity Score and Sustainable Healthy Diet Score, respectively, on FRANI.

The primary outcome was the feasibility of FRANI as measured by adherence, acceptability and usability during the feasibility period (the last two weeks of the study), when participants from both groups used gamified FRANI. Adherence was defined as the number of completed daily dietary recalls divided by the total number of dietary recalls. Participants were considered having complete dietary recalls if all meals were recorded and considered having incomplete dietary recalls if any meal was not recorded. Participants which record was of zero meal on a given day were also considered having an incomplete recall. A target equal to or greater than 70% was defined *a priori* as necessary for the group of participants to be considered adherent based on a literature review (Braga et al., 2021). Acceptability and usability were assessed using a questionnaire based on a Likert scale from 1 (strongly agree) to 5 (strongly disagree) at the end of the feasibility period. Acceptability related to issues of likeability and satisfaction, while usability related to use and intent to continue using FRANI beyond the study period. FRANI was considered acceptable or usable if the sum of points was 30 or less on a scale from 10 to 50 points.

Data analysis

Descriptive statistics summarize household and parents socio-economic characteristics, as well as adolescents' smartphone use for intervention and control groups**.** The effect of gamified FRANI on dietary quality was calculated with food consumption data from the randomized pilot period (first four weeks of the study), when participants had different versions of FRANI. Poisson regression models with random effects accounted for the repeated measures at the individual level. The bivariate regression had intervention (use of gamified FRANI) as the only independent variable, while the multivariate regression added time and the interaction of time and intervention. Description of changes in best-fit multilevel models over the course of gamified health interventions had a time-variant predictor (Allam et al., 2015). An exploratory analysis estimated the effects of the intervention on the probability of consumption of each food group of the MDDW and ELDS separately using logistic models. The data analyses were by intent to treat, and a p-value <0.05 was considered statistically significant.

There were two main indicators for dietary quality. The Minimum Dietary Diversity for Women (MDDW) has validated micronutrient adequacy for women at

reproductive age using a count from 0 to 10 of food groups consumed (Arimond et al., 2010; WDDP Study Group, 2017). The EAT-Lancet Diet, validated for women at reproductive age in Vietnam, was developed to measure dietary quality based on the appropriate level of consumption of 14 food groups to promote human and environmental health (Knuppel et al., 2019; Hanley-Cook et al., 2021; Willet et al., 2019). The Global Diet Quality Score (GDQS) is the only indicator validated for dietary quality outcomes related to both nutrient adequacy and non-communicable disease for women of reproductive age globally; but was included only as exploratory analysis since it was published after this study was preregistered (Bromage, 2021). The GDQS ranges from 0 to 49 points according to the quantity consumed of 25 food group (16 healthy, 7 unhealthy and 2 unhealthy when consumed excessively) (Bromage, 2021). Dietary data collected by the participants was automatically separated into foods, and these foods classified according to food groups of the MDDW, ELDS and the GDQS. The number of unique food groups consumed of each indicator was automatically summed daily and shown to the participants in the home dashboard and statistic page. The results of this process were double-checked by our team.

Ethical approval

The study was approved by the Institutional Review Board (IRB) of the International Food Policy Research Institute on April 29, 2020 (registration number #00007490) and the Thai Nguyen National Hospital on April 14, 2020 (protocol code 274/ĐĐĐ-BVTWTN). The study was registered in the International Standard Randomized Controlled Trial Number on November 12, 2021 (ISRCTN #10681553; https://doi.org/10.1186/ISRCTN10681553) and the protocol for this study was published on December 6, 2022 in Frontiers in Digital Health (https://doi.org/10.3389/fdgth.2022.961604) . All procedures were in accordance with the Declaration of Helsinki.

3. Results

Food consumption trends

The randomized pilot period had a total of 995 participant-days. According to the MDDW food groups, 91.7% of the participant-days ate grains, 93.3% ate meat and fish, and 86.5% ate other vitamin-A rich vegetables, but only 10.2% ate nuts, 16.8% ate dairy, 25.7% ate pulses and 29.6% ate eggs. According to the ELDS, all participant-days consumed a healthy amount of fat, 63.8% consumed a healthy amount of fish, beef or poultry, while only 2.2% ate a healthy amount of nuts, 7.8% of beans, 14.1% consumed a healthy amount of vegetables, 15.0% of fruits, and 15.5% of eggs. All food groups of the GDQS but high diary fat classified consumption as low, middle or high. The low consumption of healthy foods was between 40.3% for liquid oils and 100% for orange tubers; low consumption of unhealthy foods was between 82.4% for refined grains and baked goods and 100% for sugar-sweetened beverage and for fruit juice. The majority of the sample did not consume most food groups of the MDDW or ELDS for most days, but there was a high between-day variability. Figure 4 shows the share of participant who ate each food group by intervention group.

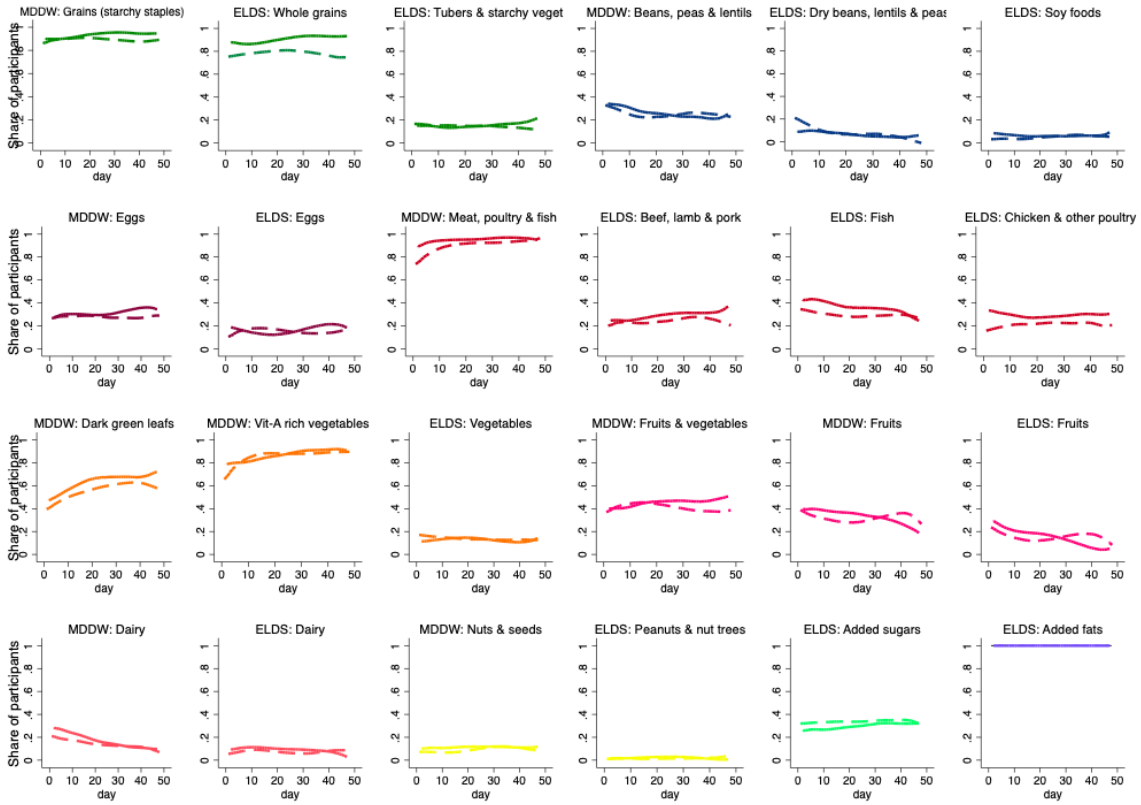
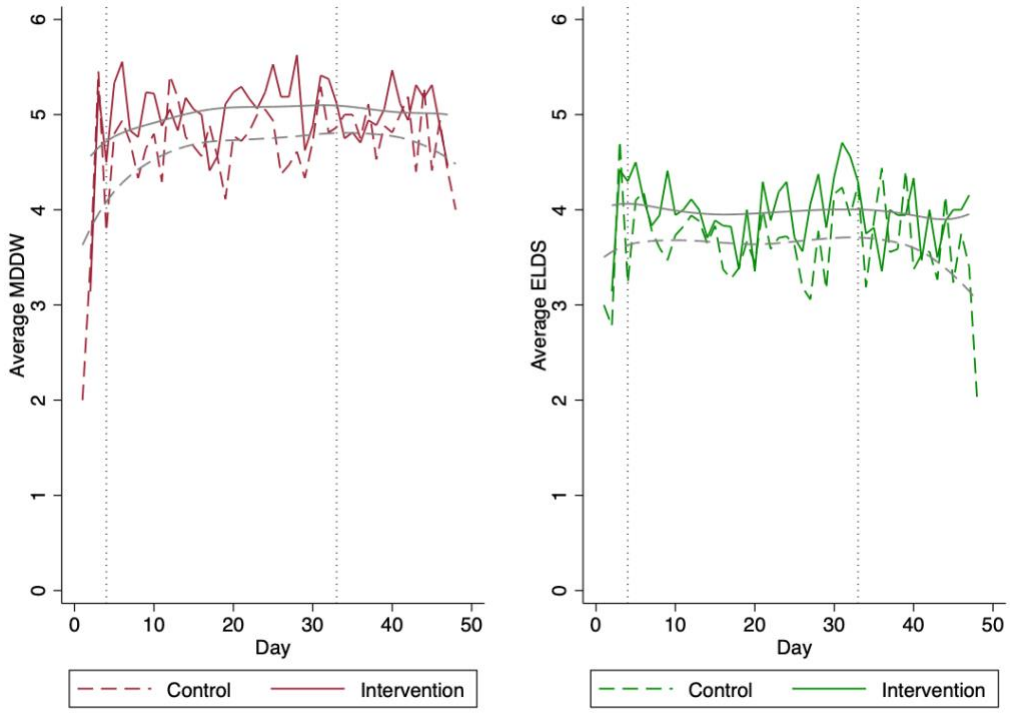


Figure 4: Share of participants who consumed each of the food groups of the MDDW and the ELDS per day during the whole study period. Solid lines are for intervention and dashed are for control group. Colors divide types of food groups.

Effects of FRANI on food consumption

Groups were balanced before the start of the study period for all variables but number of people who lived in the household (household size). The socio-demographic and phone use characteristics of the groups are described in Table 1. Participants in the intervention group had higher MDDW (B=1.714 points, CI 95% [0.979; 1.178]; p=0.131) and ELDS (B=1.092 points, CI 95% [1.008; 1.183]; p=0.032), with no evidence of an interaction between intervention status and time (Table 2). The constant of the MDDW was higher than ELDS because food group consumption has to be within a specific quantity interval only for the later. Household size was included in the regressions to account for difference in baseline between intervention and control, but did not change the results (Appendix 3). The findings of the exploratory analysis on food group consumption suggested that participants using gamified FRANI had higher odds of

consuming all MDDW food groups, but the effects were not significant (Appendix 4). The interaction between intervention and time significantly increased the odds of consuming grains (B=1.098, CI 95% [1.030; 1.171]; p=0.004). Participants using the gamified FRANI also had higher odds of achieving eight of the 14 food group scores of the ELDS (Appendix 5). The effects on the food group scores for rice, wheat, corn and other (B=2.362, CI [1.129; 4.944]; p=0.023); and fish (B=1.509, CI [0.992; 2.293], p=0.054) were statistically significant. The effect of gamified FRANI on the GDQS and its food groups are in Appendix 6, 7a, 7b and 7c, respectively.



Figures 5: MDDW and ELDS daily averages. Green curves are for the MDDW and maroon are for the ELDS. Solid lines are for intervention and dashed are for control group. Gray lines are lowess curves, that show trends. From left to right, horizontal reference lines mark the start of the randomized pilot period, and the end of randomized periods and start of the feasibility period.

Adherence, acceptability and usability of FRANI

The feasibility study period included 412 completed dietary recalls over a total of 504 participant-days, an adherence of 82% (Figure 5). During the randomized pilot

period, the control group completed 473 dietary recalls and the intervention group completed 439 of the 540 participant-days per group, an adherence of 87.6% and 81.3% respectively. During the whole study period, there were 1,304 complete dietary recalls over a total of 1,548 participant-days (36 participants and 43 days), an adherence of 84.4%. The percentage of meals recorded stayed between 96.5% and 97% independently of group and period considered. The number of complete dietary recalls per day, adherence and percentage of meals recorded are illustrated in Figure 6. Out of the 36 participants, 35 deemed FRANI as acceptable and 35 deemed FRANI as usable. Acceptability and usability were 94.4% in the control and 100% in the intervention group. Acceptability and usability questions and answers are summarized in Table 3.

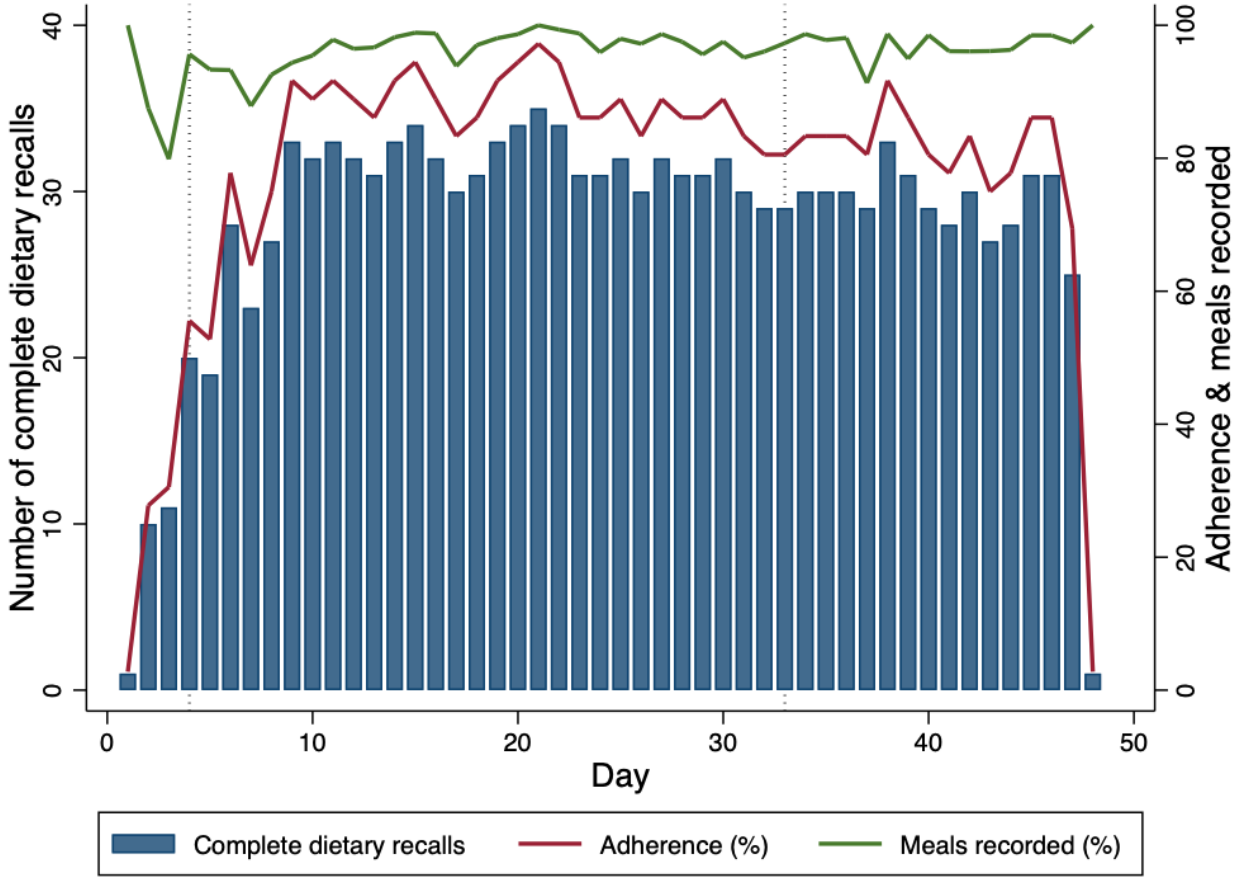


Figure 6: Number of complete dietary recalls, adherence (percentage of complete dietary recalls) and percentage of meals recorded per day. The first vertical bar from left to right marks the start of the randomized controlled pilot period, and the second marks the end of the randomized pilot and the start of the feasibility period.

4. Discussion

Nutrition during adolescence is critical for development and health (Norris et al., 2021; Falconi et al., 2014; Depauw & Oxley, 2019). Addressing the pervasive worldwide neglect on adolescent nutrition requires accurate data to inform targets, track trends and identify intervention priorities (Hargreaves et al., 2022). Smartphone has enormous potential as instrument of data collection (Bromage, 2021), while smartphone-based interventions can help on food choice (Anderson & Jiang, 2018; Lenhart et al., 2015). FRANI is able to accurately monitor diet in Vietnam with its innovative technology of food image recognition. Southern Asia along with sub-Saharan Africa account for the largest share of the global burden of undernutrition, and the slowest reduction in food insecurity in the recent decades (FAO, 2015). To our knowledge, this is the first study to assess the feasibility and impact of using an AI-assisted smartphone application to improve the dietary quality of female adolescents in low- and middle-income countries previously validated for dietary assessment (Nguyen et al., 2021).

Our findings highlight that FRANI is feasible. There was high adherence and percentage of meals recorded, but a slight downward trend with time. Previous research have shown that recording dietary intake with mobile phones over longer periods is possible, but is not yet clear what features foster that (Sharp & Allman-Farinelli, 2014). Previous focus groups discussions showed that using FRANI at school and home could be challenging, since phones are discouraged in the former and separation of individual food portions from shared meals was considered disrespectful to family members (Braga et al., 2022). The acceptability and usability questionnaire results showed that the vast majority of participants were able to take the pictures at home and school, indicating that the teachers and family supported the use of FRANI. The control group completed more dietary recalls than the intervention group during both the randomized pilot and the feasibility periods. This might be other due to the small sample size, to the control group inputting less the number of meals not recorded at the end of each day or a potential fatigue caused by the gamified feature during the first two thirds of the study period. There was high acceptability and usability in general, and the only two participants that did not consider FRANI acceptable or usable were from the control group. The results showed that participants trusted information on healthy eating and feedback on their diet

from FRANI. Adolescents are particularly sensitive and selective about information to finally make their own decisions and form lifelong habits (Neufeld et al., 2022). That facilitates food promotion of various sources including from pervasive industry marketing to science-based apps (Aboujaoude et al., 2015; O'Keeffe & Clarke-Pearson, 2011; Starcevic & Aboujaoude, 2015).

Evidence suggests that gamified FRANI increased the MDDW and the ELDS, although the impact on the former was not significant. Exploratory analysis indicated that improvement in dietary quality in the intervention group were driven by consumption of micronutrient-rich foods. Prior to the use of FRANI, participants did not know what to make of nutrition and health messages (Braga et al., 2022). The literature shows that effective communication on nutrition literacy does not happen by pushing messages into people (Azevedo Perry et al., 2017; Cullen et al., 2015; Truman et al., 2017; Velardo, 2015). Acting on information requires comprehension, and the most effective way of learning is through experience (Dudley et al., 2015). The impact of FRANI in behavior change may be attributed to experiential learning. The game elements worked as practical instead of theoretical knowledge in the form of badges and statistics. The knowledge from this feedback could be incorporated to the food choices of the next meal so to achieve new goals. FRANI social media features such as sharing badges with friends and receiving positive feedback-only from peers were well-received, corroborating previous qualitative findings (Braga et al., 2022). Adolescents have deep need for social connection, exploration and autonomous identity (Montgomery et al., 2012). To avoid cyberbullying, it was not possible to make write comments on FRANI because adolescents are easily influenced by peers (Tremblay & Lariviere, 2009; Contento et al., 2006). Participants felt praised and supported by FRANI friends. It is possible that gamification sustained behavior change by activating the desired social norms when participants competed and cooperated to achieve team-based goals (Azevedo et al., 2019; Higgs & Ruddock, 2020). Gamification may have also allowed self-efficacy by peer modeling, the observation that one can master an activity if others are mastering it too (Bandura et al., 1997).

The main strengths of this study are the randomized design using an app developed according to input of potential users that was previously validated for dietary

assessment in the population of interest (Braga et al., 2022; Nguyen et al., 2022). This resulted in high adherence throughout the pilot period which in turn led to an unprecedented dataset with six full weeks of food consumption records. The success of data collection may be in part attributed to the teachers and research personnel, that prompted the participants in person weekly to collect data. An important limitation of the study from the internal validity perspective is its small sample size, that may explain the insignificance of the impact of gamified FRANI on the MDDW. In addition, the study sample was randomly drawn from a population of adolescents enrolled in one high school, and thus has limited external validity. The next steps of this project are to assess the potential of FRANI to have an impact at scale in different contexts and do a cost-effectiveness analyses.

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Table 1: Characteristics of the pilot study participants, their parents and households (N=36)

Characteristics of the household and participants	Control (%)	Intervention (%)	P-value	Characteristics of the parents	Control (%)	Intervention (%)	P-value
Household size (mean (SD))	5.1 (1.5)	4.2 (0.9)	0.026*	Mother's education (N(%))			0.264
Household assets				Less than high school	4 (22.2)	4 (22.2)	
TV	17 (94.4)	18 (100)	0.349	High school	12 (66.7)	8 (44.4)	
Computer	10 (55.6)	13 (72.2)	0.710	College	2 (11.1)	5 (27.8)	
Refrigerator/freezer	18 (100)	18 (100)	0.460	Post-Graduate	0 (0)	1 (5.6)	
Air conditioners	11 (61.1)	10 (55.6)	0.491	Father's education (N(%))			0.756
Washing machine	16 (88.9)	15 (83.3)	0.217	Less than high school	7 (38.9)	10 (58.9)	
Gas cooker/stove	18 (100)	18 (100)	0.623	High school	10 (55.6)	5 (29.4)	
Bicycle	11 (61.1)	14 (77.8)	0.112	College	1 (5.6)	1 (5.9)	
Electric bicycle	7 (38.9)	8 (44.4)	0.558	Post-Graduate	0 (0.0)	1 (5.9)	
Motorcycle	18 (100)	18 (100)	0.043	Mother's occupation			0.594
Water heater	17 (94.4)	17 (94.4)	0.710	Farmer	2 (11.1)	6 (33.3)	
Car	5 (27.7)	1 (5.6)	0.191	Blue-collar worker	5 (27.8)	2 (11.1)	
Uses smartphone	15 (83.3)	16 (88.9)	0.764	White-collar worker	1 (5.6)	2 (11.1)	
Uses smartphone 5-7 times/week	17 (94.4)	18 (100)	0.324	Unskilled worker	9 (50.0)	5 (27.8)	
Reason to use phone				Stay-at-home parent	0 (0)	1 (5.6)	
Call	16 (88.9)	15 (83.3)	0.641	Other	1 (5.6)	2 (11.1)	
Messaging	17 (94.4)	16 (88.9)	0.560	Father's occupation			0.566
Listen to music	18 (100)	18 (100)	0.154	Farmer	2 (11.1)	4 (23.5)	
Movie	18 (100)	18 (100)	0.324	Blue-collar worker	4 (22.2)	4 (23.5)	
Game	23 (63.9)	12 (66.7)	0.738	White-collar worker	2 (11.1)	2 (11.8)	
Social media	18 (100)	18 (100)	.	Unskilled worker	8 (44.4)	6 (35.3)	
Internet (news)	18 (100)	16 (88.9)	0.154	Stay-at-home parent	0 (0)	0 (0)	
For learning	18 (100)	15 (83.3)	0.074	Other	2 (11.1)	1 (5.9)	
Other	6 (42.9)	2 (16.7)	0.161				

Note: Excellent school performance is defined as average grades of nine or above out of ten. Social media is Facebook, Twitter and Zalo. Only household size was different between groups. Groups were balanced for all variables but household size prior to the start of the study.

Table 2: Impact of the intervention, time and the interaction of intervention and time on the Minimum Dietary Diversity for Women and the Eat-Lancet Diet Score.

	MDDW (1)	MDDW (2)	ELDS (3)	ELDS (4)
Intervention	1.074	1.074	1.092	1.071
CI	[0.979; 1.178]	[0.918; 1.257]	[1.008; 1.183]	[0.909; 1.261]
P-value	0.131	0.371	0.032*	0.412
Time		1.002		1.000
CI		[0.997; 1.006]		[0.995; 1.006]
P-value		0.522		0.784
Intervention-time		1.000		1.001
CI		[0.993; 1.007]		[0.994; 1.009]
P-value		0.995		0.785
Constant	4.675	4.540	3.673	3.621
Observations	n=995	n=995	n=995	n=995

Note: MDDW: Minimum Dietary Diversity for Women. ELDS: Eat-Lancet Diet Score. CI=confidence interval. SE=standard error. Results of the Poisson models with incidence rate ratios and 36 clusters, one for each participant.**1% significance; *5% significance. The intervention group used gamified FRANI. Time is the effect of using FRANI throughout the randomized study period. Models 1 and 3 have intervention as independent variable; models 2 and 4 also include time, and the interaction of intervention and time.

Table 3: Agreement with acceptability and usability statements about FRANI

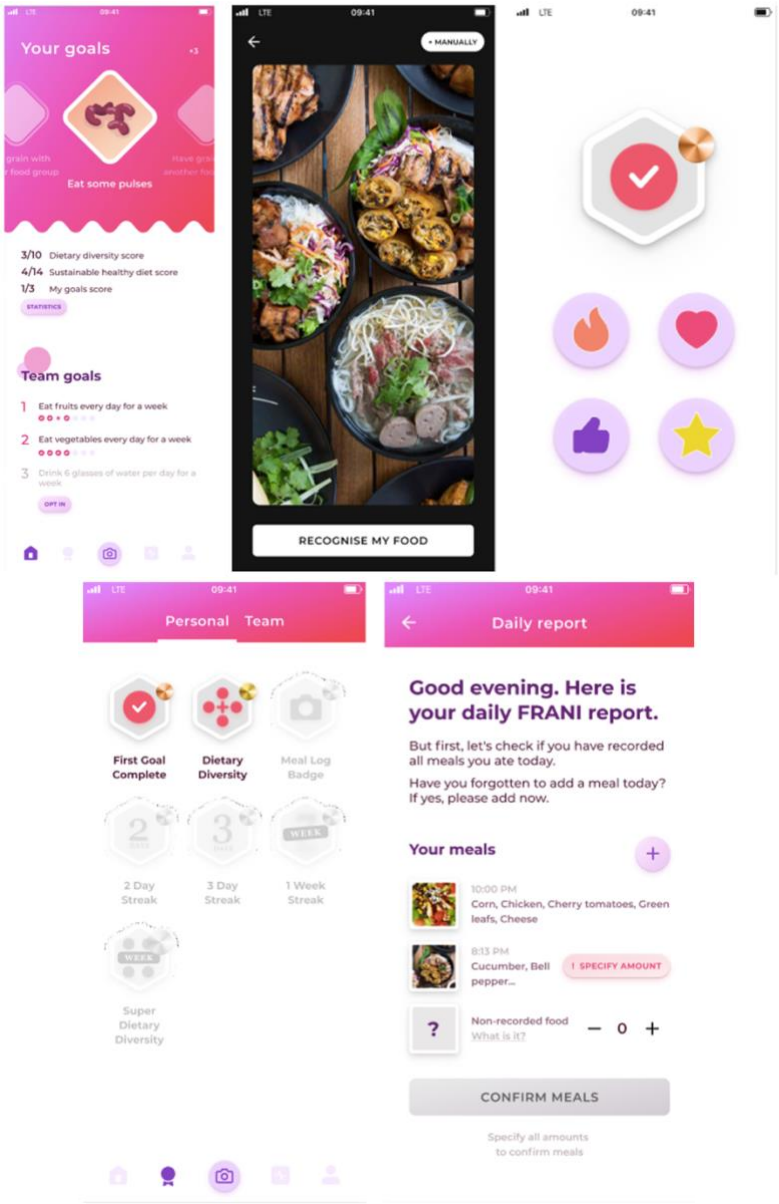
	Strongly agree	Agree	Neither	Disagree	Strongly disagree
Acceptability statements N (%)					
I like this app	8 (22.2)	24 (66.7)	4 (11.1)	0 (0)	0 (0)
I want to keep using this app	2 (5.6)	21 (58.3)	11 (30.6)	2 (5.6)	0 (0)
This app helps me to eat healthy	6 (16.7)	23 (63.9)	4 (11.1)	3 (8.3)	0 (0)
I like receiving badges	9 (25)	24 (66.7)	3 (8.3)	0 (0)	0 (0)
I like the daily diet reports	4 (11.1)	28 (77.8)	4 (11.1)	0 (0)	0 (0)
I like the daily statistics page	7 (19.4)	21 (58.3)	6 (16.7)	2 (5.6)	0 (0)
I like the weekly statistics page	7 (19.4)	22 (61.1)	6 (16.7)	1 (2.8)	0 (0)
I like following other users	2 (5.6)	21 (58.3)	10 (27.8)	3 (8.3)	0 (0)
I like to be part of a team	1 (2.8)	25 (69.4)	10 (27.8)	0 (0)	0 (0)
I like the general navigation of the screens	6 (16.7)	20 (55.6)	9 (25)	1 (2.8)	0 (0)
Usability statements N (%)					
This app is simple to understand	15 (41.7)	17 (47.2)	2 (5.6)	2 (5.6)	0 (0)
I felt comfortable using this app	7 (19.4)	19 (52.8)	9 (25)	1 (2.8)	0 (0)
I felt praised when I ate healthy foods	13 (36.1)	18 (50)	5 (13.9)	0 (0)	0 (0)
I felt supported by my app friends	4 (11.1)	18 (50)	11 (30.6)	3 (8.3)	0 (0)
I can take pictures of my meals at home	10 (27.8)	24 (66.7)	2 (5.6)	0 (0)	0 (0)
I can take pictures of my meals in school	6 (16.7)	19 (52.8)	8 (22.2)	3 (8.3)	0 (0)
My family lets me take pictures of my meals	10 (27.8)	25 (69.4)	1 (2.8)	0 (0)	0 (0)
I can separate only what I eat to take pictures	6 (16.7)	20 (55.6)	6 (16.7)	4 (11.1)	0 (0)
I trust this app's information about healthy eating	12 (33.3)	21 (58.3)	3 (8.3)	0 (0)	0 (0)
I trust this app's feedback about my diet	14 (38.9)	21 (58.3)	1 (2.8)	0 (0)	0 (0)

Note: Likert answers are in number (percentage) of participants.

Appendix 1: Characteristics of FRANI by level of functionality

	Gamified	Limited
Account registration and login	Available	Available
Home dashboard	Available	N/A
Setting goals	Available	N/A
Meal entry (picture taking)	Available	Available
Scores and statistics	Available	N/A
Medals and badges	Available	N/A
Daily report	Available	N/A
Activity feed	Available	Modified
Notification	Available + Daily report reminder	Available

Note: N/A stands for not available. The daily report was available at the end of each day on FRANI and was sent as a notification.



Appendix 2: From left to right, top to bottom: Wireframe one shows the home dashboard with dietary scores and two is the camera frame. Wireframe three shows the confirmation that the foods were uploaded with a bronze badge and four shows individual-based badges. Five shows FRANI daily report sent in the evening so users can include, complete or correct information on food consumption uploaded throughout the day.

Appendix 3: Impact of the intervention, time, the interaction of intervention and time and household size on the Minimum Dietary Diversity for Women and the Eat-Lancet Diet Score.

	MDDW (1)	MDDW (2)	ELDS (3)	ELDS (4)
Intervention	1.085	1.085	1.114	1.092
CI	[0.983;1.199]	[0.924; 1.274]	[1.024; 1.212]	[0.926; 1.289]
P-value	0.106	0.319	0.012**	0.297
Time		1.002		1.001
CI		[0.997; 1.006]		[0.995; 1.006]
P-value		0.526		0.801
Intervention-time		1.000		1.001
CI		[0.993; 1.007]		[0.994; 1.009]
P-value		0.994		0.782
Household size	1.011	1.011	1.022	1.022
CI	[0.973; 1.052]	[0.972; 1.052]	[0.989; 1.057]	[0.988; 1.057]
P-value	0.572	0.582	0.197	0.201
Constant	4.414	4.290	3.285	3.245
Observations	n=995	n=995	n=995	n=995

Note: MDDW: Minimum Dietary Diversity for Women. ELDS: Eat-Lancet Diet Score. CI=confidence interval. SE=standard error. Results of the Poisson models with incidence rate ratios and 36 clusters, one for each participant.*5% significance; **1% significance. The intervention group used gamified FRANI. Time is the effect of using FRANI throughout the randomized study period. Models 1 and 3 have intervention as and household size as independent variable; models 2 and 4 also include time, and the interaction of intervention and time.

Appendix 4: Impact of the intervention, time and the interaction of intervention and time on each food group of the Minimum Dietary Diversity Score

	Grains (1)	Pulses (2)	Nuts and seeds (3)	Dairy (4)	Meat, poultry and fish (5)	Eggs (6)	Dark green vegetables (7)	Other vit-A rich FV (8)	Other vegetables (9)	Other fruits (10)
Univariate										
Intervention	1.629	1.195	1.340	1.643	2.167	1.140	1.503	1.086	0.772	1.583
CI	0.441; 6.017	0.758; 1.883	0.696; 2.580	0.694; 3.894	0.956; 4.912	0.669; 1.943	0.686; 3.292	0.691; 1.708	0.383; 1.553	0.867; 2.891
P-value	0.465	0.444	0.381	0.259	0.064	0.631	0.309	0.720	0.467	0.135
Constant	21.450	0.292	0.078	0.105	13.363	0.358	1.250	0.749	9.211	0.321
Multivariate										
Intervention	0.352	1.801	2.179	2.554	3.958	1.239	1.441	0.768	0.452	1.403
CI	0.066; 1.887	0.814; 3.986	0.630; 7.533	0.801; 8.149	0.953; 16.442	0.541; 2.837	0.521; 3.984	0.368; 1.605	0.153; 1.338	0.587; 3.357
P-value	0.223	0.147	0.218	0.113	0.058	0.612	0.482	0.483	0.152	0.446
Time	0.993	1.004	1.040	0.972	1.037	0.999	1.034	0.995	1.004	0.994
CI	0.956; 1.032	0.980; 1.030	1.001; 1.082	0.940; 1.005	0.997; 1.078	0.975; 1.024	1.010; 1.060	0.973; 1.017	0.971; 1.038	0.970; 1.019
P-value	0.728	0.729	0.047*	0.093	0.067	0.957	0.006**	0.639	0.830	0.638
Intervention-time	1.098	0.978	0.977	0.974	0.967	0.995	1.004	1.019	1.031	1.006
CI	1.030; 1.171	0.944; 1.013	0.928; 1.028	0.931; 1.018	0.906; 1.032	0.962; 1.030	0.969; 1.040	0.988; 1.051	0.984; 1.079	0.973; 1.041
P-value	0.004**	0.212	0.372	0.246	0.311	0.793	0.840	0.479	0.197	0.711
Constant	24.700	0.268	0.035	0.176	6.977	0.363	0.659	0.827	8.605	0.360

Note: CI=confidence interval. SE=standard error. FV is fruits and vegetables. Intervention-time is the interaction variable between intervention and time. **1% significance; *5% significance. Results of Logistic models for the 10 food groups that compose the MDDW with 995 participant-days and 36 clusters. Data included were from the first four weeks of the pilot study, when the intervention group used FRANI with full functionality, and the control group used FRANI with limited functionality. Time is the effect of using FRANI throughout the study period. Univariate models have intervention as independent variable; multivariate models also include time, and the interaction of intervention and time. Grains include grains, white roots, and tubers and plantains. Pulses are beans, peas and lentils.

Appendix 5: Impact of the intervention, time and the interaction of intervention and time on each food group of the Eat-Lancet Diet Score

	Rice, wheat, corn and other (1)	Potatoes and cassava (2)	Dry beans, lentils and peas (3)	Soy foods (4)	Peanuts and tree nuts (5)	Whole milk or derivative equivalents (6)	Beef, lamb, pork (7)	Chicken and other poultry (8)	Fish (9)	Eggs (10)	All vegetables (11)	All fruits (12)	All sweeteners (13)
Univariable													
Intervention	2.362	0.951	0.953	1.626	1.801	1.596	1.271	1.534	1.509	0.802	0.965	1.529	0.849
CI	1.129; 4.944	0.522; 1.731	0.451; 2.013	0.682; 3.875	0.430; 7.542	0.713; 3.575	0.920; 1.757	0.940; 2.505	0.992; 2.293	0.458; 1.403	0.326; 2.861	0.667; 3.503	0.554; 1.299
P-value	0.023**	0.869	0.899	0.273	0.421	0.255	0.147	0.087	0.054**	0.438	0.949	0.316	0.451
Constant	5.044	0.156	0.063	0.033	0.007	0.054	0.320	0.268	0.395	0.176	0.085	0.077	0.485
Multivariable													
Intervention	1.126	0.801	0.980	4.091	1.448	1.251	1.178	1.807	1.924	0.640	0.641	2.593	0.560
CI	0.379; 3.341	0.294; 2.178	0.285; 3.369	0.761; 21.998	0.099; 21.218	0.359; 4.360	0.566; 2.453	0.790; 4.136	0.922; 4.017	0.245; 1.672	0.157; 2.620	0.739; 9.103	0.264; 1.190
P-value	0.831	0.663	0.974	0.101	0.787	0.726	0.662	0.161	0.608	0.363	0.536	0.137	0.132
Time	1.016	0.998	0.969	1.055	1.028	0.962	1.017	1.012	0.994	0.988	0.987	1.028	0.998
CI	0.988; 1.045	0.968; 1.028	0.931; 1.009	0.999; 1.113	0.943; 1.120	0.922; 1.004	0.993; 1.043	0.986; 1.038	0.971; 1.018	0.959; 1.017	0.953; 1.022	0.992; 1.066	0.976; 1.021
P-value	0.264	0.889	0.124	0.052**	0.535	0.076	0.171	0.389	0.608	0.397	0.449	0.132	0.877
Intervention-time	1.047	1.009	0.998	0.957	1.011	1.014	1.004	0.992	0.987	1.012	1.022	0.974	1.022
CI	0.997; 1.098	0.967; 1.053	0.941; 1.057	0.894; 1.024	0.907; 1.127	0.959; 1.072	0.971; 1.039	0.958; 1.027	0.955; 1.019	0.970; 1.056	0.974; 1.0722	0.928; 1.021	0.990; 1.056
P-value	0.064	0.673	0.935	0.205	0.844	0.625	0.803	0.637	0.421	0.577	0.371	0.271	0.186
Constant	3.738	0.162	0.112	0.011	0.004	0.108	0.229	0.215	0.443	0.222	0.109	0.045	0.501

Note: Results of Logistic models with 36 clusters and 995 participant-days for the all food groups that compose the Eat-Lancet Diet Score (ELDS) but fat since the outcome did not vary for this food group. CI=confidence interval. SE=standard error. **1% significance; *5% significance. The intervention group used gamified FRANI. Univariable models have intervention as independent variable; multivariable models also include time, and the interaction of intervention and time.

Appendix 6: Impact of the intervention, time and the interaction of intervention and time on the Global Diet Quality Score.

	GDQS (1)	GDQS (2)	GDQS+ (3)	GDQS+ (4)	GDQS- (5)	GDQS- (6)
Intervention	1.017	0.998	1.042	1.025	0.997	0.980
CI	[0.956; 1.082]	[0.911; 1.094]	[0.816; 1.329]	[0.780; 1.349]	[0.962; 1.039]	[0.899; 1.069]
P-value	0.595	0.968	0.744	0.858	0.868	0.647
Time		0.999		1.000		0.999
CI		[0.997; 1.002]		[0.995; 1.000]		[0.996; 1.002]
P-value		0.600		0.956		0.559
Intervention-time		1.000		1.000		1.001
CI		[0.997; 1.005]		[0.994; 1.007]		[0.997; 1.005]
P-value		0.587		0.804		0.672
Constant	17.209	17.434	4.609	4.621	12.416	12.628
Observations	n=992	n=992	n=992	n=992	n=992	n=992

Note: GDQS: Global Diet Quality Score. CI=confidence interval. SE=standard error. Results of the Poisson models with incidence rate ratios and 36 clusters, one for each participant. The intervention group used the gamified FRANI. Time is the effect of using FRANI throughout the study period. All models have intervention as independent variable; models 2, 4 and 6 also include time, and the interaction of intervention and time. The GDQS+ is the total score of the healthy food groups with a possible range from 0 to 32, while the GDQS- is the total score of the unhealthy food groups, with a range between 0 to 17 (Bromage, 2021).

Appendix 7a: Impact of the intervention, time and the interaction of intervention and time on each food group of the Global Diet Quality Score

	Citrus fruits	Deep orange fruits	Other fruits	Dark green leafy vegetables	Cruciferous vegetables	Deep orange vegetables	Other vegetables	Legumes
Univariable								
Intervention	0.988	1.969	1.345	0.958	1.079	1.303	0.728	1.072
CI	0.198; 4.918	0.590; 6.567	0.580; 3.122	0.416; 2.208	0.460; 2.532	0.678; 2.504	0.410; 1.294	0.745; 1.542
P-value	0.988	0.270	0.490	0.920	0.862	0.428	0.280	0.710
Constant	0.006	0.015	0.173	0.698	0.111	0.095	0.731	0.273
Multivariable								
Intervention	0.115	1.253	1.656	0.701	0.792	0.505	0.778	1.150
CI	0.002; 7.905	0.209; 7.500	0.542; 5.057	0.245; 2.006	0.233; 2.695	0.169; 1.506	0.337; 1.798	0.541; 2.445
P-value	0.316	0.805	0.376	0.508	0.709	0.220	0.557	0.717
Time	0.947	0.920	1.003	1.005	1.002	0.962	0.996	0.990
CI	0.821; 1.092	0.859; 0.987	0.975; 1.032	0.980; 1.030	0.970; 1.036	0.927; 0.997	0.973; 1.019	0.964; 1.016
P-value	0.454	0.019**	0.826	0.698	0.885	0.036**	0.713	0.431
Intervention-time	1.120	1.031	0.989	1.017	1.016	1.053	0.996	0.996
CI	0.915; 1.371	0.945; 1.125	0.951; 1.028	0.983; 1.051	0.971; 1.063	1.003; 1.106	0.965; 1.029	0.961; 1.032
P-value	0.272	0.496	0.575	0.328	0.483	0.036**	0.825	0.824
Constant	0.016	0.055	0.163	0.636	0.105	0.192	0.793	0.331

Appendix 7b: Impact of the intervention, time and the interaction of intervention and time on each food group of the Global Diet Quality Score

	Nuts and seeds	Whole grains	Liquid oils	Fish and shellfish	Poultry and game meats	Low-fat dairy	Eggs
Univariable							
Intervention	1.156	5.096	0.988	1.102	1.238	2.901	1.102
CI	0.625; 2.139	0.545; 47; 68	0.555; 1.757	0.585; 2.076	0.720; 2.127	0.206; 40.861	0.674; 1.801
P-value	0.644	0.154	0.967	0.763	0.440	0.430	0.699
Constant	0.121	0.002	1.539	0.178	0.221	0.001	0.282
Multivariable							
Intervention	0.494	1.829	1.551	0.632	2.327	0.502	1.044
CI	0.174; 1.406	0.021; 160.413	0.669; 3.594	0.232; 1.723	0.927; 5.840	0.003; 81.500	0.456; 2.390
P-value	0.187	0.791	0.306	0.370	0.072	0.791	0.919
Time	0.973	0.892	1.011	0.993	1.033	0.808	0.995
CI	0.941; 1.006	0.667; 1.192	0.988; 1.035	0.964; 1.022	1.004; 1.062	0.535; 1.220	0.970; 1.021
P-value	0.111	0.438	0.337	0.615	0.023*	0.310	0.701
Intervention-time	1.047	1.074	0.976	1.030	0.968	1.163	1.003
CI	1.000; 1.095	0.788; 1.465	0.945; 1.008	0.989; 1.072	0.932; 1.006	0.751; 1.801	0.968; 1.039
P-value	0.049*	0.650	0.147	0.157	0.097	0.499	0.877
Constant	0.199	0.009	1.244	0.205	0.117	0.012	0.310

Note: GDQS=Global Diet Quality Score. CI=confidence interval. SE=standard error. **1% significance; *5% significance. Results of Logit models with 36 clusters and 995 participant-days for healthy food groups that compose the Global Diet Quality Score. Deep orange tubers was not reported since the outcome did not vary. The intervention group used gamified FRANI. Univariable models have intervention as independent variable; multivariable models also include time, and the interaction of intervention and time.

Appendix 7c: Impact of the intervention, time and the interaction of intervention and time on each food group of the Global Diet Quality Score

	High-fat dairy	Red meat	Processed meat	Refined grains and baked goods	Sweets and ice creams	Sugar-sweetened beverages	Juice	White roots and tubers	Purchased deep fried foods
Univariable									
Intervention	1.277	1.198	1.594	0.479	1.258	1.012	1 (omitted)	3.229	1 (omitted)
CI	0.470; 3.473	0.698; 2.054	0.404; 6.290	0.156; 1.473	0.342; 4.629	0.063; 16.226	-	0.543; 19.206	-
P-value	0.632	0.512	0.505	0.199	0.730	0.993	-	0.198	-
Constant	0.023	1.926	53.946	0.163	90.469	491.955	245.500	108.137	163.333
Multivariable									
Intervention	0.962	0.575	0.197	0.742	0.089	0.113	1 (omitted)	116.003	1 (omitted)
CI	0.180; 5.125	0.251; 1.314	0.023; 1.672	0.183; 3.003	0.007; 1.150	0.000; 200.579	-	0.221; 60956.3	-
P-value	0.964	0.189	0.136	0.675	0.064	0.568	-	0.137	-
Time	0.946	0.987	0.952	0.990	1.004	0.941	0.933	0.943	1.015
CI	0.888; 1.007	0.964; 1.011	0.900; 1.007	0.961; 1.020	0.928; 1.088	0.729; 1.214	0.776; 1.121	0.873; 1.017	0.885; 1.163
P-value	0.081	0.298	0.085	0.520	0.914	0.640	0.459	0.129	0.835
Intervention-time	1.017	1.040	1.121	0.975	1.223	1.122	1 (omitted)	0.870	1 (omitted)
CI	0.936; 1.106	1.006; 1.076	1.023; 1.228	0.930; 1.022	1.022; 1.464	0.786; 1.600	-	0.700; 1.081	-
P-value	0.691	0.021*	0.014*	0.292	0.028*	0.527	-	0.211	-
Constant	0.059	2.456	151.803	0.196	94.251	1771.916	1081.188	379.035	125.043

Note: Note: CI=confidence interval. GDQS=Global Diet Quality Score. Results of Logit models with 36 clusters and 995 participant-days for the unhealthy food groups of the GDQS. CI=confidence interval. SE=standard error. **1% significance; *5% significance. The intervention group used gamified FRANI. Univariable models have intervention as independent variable; multivariable models also include time, and the interaction of intervention and time.

Chapter 7: Conclusion

Food environments have long been characterized as being comprised of economic, political, socio-cultural and physical dimensions that affect food choices and nutritional status (Swinburn et al., 2013). There is a large body of evidence on the contribution of poor food environments to unhealthy eating (Swinburn et al., 2013), and the importance of public policy and regulation to promote healthy food environments and prevent disease (Duran et al., 2021). Recently, fiscal policies, marketing restrictions and front-of-package labeling have been implemented in many jurisdictions worldwide (Duran et al., 2021). Until now, marketing and promotions, as well as availability of nutritious food have been reported in the literature as characteristics of the physical food environments (Swinburn et al., 2013). No policy has specifically focused on digital food environments, despite its increasing importance. Digital food environments include online grocery stores, smartphone applications for restaurants, fast food delivery and ready-to-eat meal vendors, applications to monitor food consumption and give dietary advise, social media, video streaming services, online culinary and health classes, online forums and online food marketing.

There is less comprehension of digital than physical food environments because digital environments are more novel and more rapidly evolving. Digital food environments are also harder to evaluate because they are personalized, while many individuals share physical food environments. Scientific work on the regulatory aspects of online grocery stores is almost non-existent, but one study found that they fail to follow provision of nutrition information according to US regulations (Pomernanz *et al.*, 2022). This literature is mostly focused in the United States, Europe and Australia (Ang et al., 2019; Coffino et al., 2021; Ducrot et al., 2016; Egnell et al., 2021; Epstein et al., 2015; Forwood et al., 2015; Finkelstein et al., 2019; Jansen et al., 2021; Koutoukidis et al., 2019; Nederkoorn et al., 2011; Waterlander et al., 2012; Waterlander et al., 2013; Waterlander et al., 2014). Further, most studies were done in simulated online grocery stores, which have been shown to be practical and valid tools for research (Mizdrak et al., 2017; Waterlander et al., 2015; Van Herpen et al., 2016).

Studies about online grocery shopping focus mostly on the economic, labelling and educational aspects of the choice architecture of digital food environments and on food swaps. Their outcomes are quality of foods and beverages, dietary scores, nutrients and energy purchased. For example, taxes and subsidies together have been shown to increase the online purchase of healthy foods without changing the total energy (Epstein et al., 2015), while subsidies for fruits and vegetables alone have increased their online purchase (Waterlander et al., 2012). Swaps and changing the default order of the products displayed have decreased the online purchase of saturated fat, but not total energy (Huang et al., 2006; Forwood et al. 2015, Koutoukidis et al., 2019). Front-of-package labels such as traffic lights and warning labels reduced the online purchase of pre-packaged foods, unhealthy products with critical nutrients, but did not reduce the total sugar in grams and calories (Ang et al., 2019; Ducrot et al., 2016; Egnell et al., 2021). The traffic lighting and Nutri-Score labels increased the Alternative Healthy Eating Index – 2010 of foods purchased (Finkelstein et al., 2019).

Online grocery shopping is not yet common in low- and middle-income countries, but the importance of digital food environments is increasing with the phone and internet access. This is especially true for adolescents, who are early adopters of smartphones, applications, games, and social media. Although some evidence points to the impact of electronic devices on nutrition-related outcomes in adolescence for Mexico, Malaysia, Hong Kong and Thailand, the vast majority of the studies published were from the United States and Europe (Braga et al., 2021). Most interventions reported parental participation and varied vastly in terms of length and follow-up (Braga et al., 2021). The outcomes of these studies included anthropometric measures, dietary quality, biomarkers, level of physical activity, screen time and acceptability of new technologies (Braga et al., 2021). This literature showed that it is possible to increase the consumption of milk and milk alternatives, vitamin D, fruits and vegetables (Chamberland et al., 2017). Some interventions decreased others did not have a significant impact on the consumption of sugar-sweetened beverages (Champion et al., 2019; Chen et al., 2018; Jake-Schoffman et al., 2018). Most studies did not show a long-term effect of the interventions on the quality of food consumption (Chamberland et al., 2017; Champion et al., 2019). Body mass index (BMI) and BMI z-scores were reduced in intervention groups (Chen et al., 2018;

Rerksuppaphol & Rerksuppaphol, 2017), but systematic reviews have concluded that technology had small to null impact on the anthropometry of adolescents (Kaakinen et al., 2018). Physical activity and blood pressure were not impacted by technology (Abraham et al., 2015; Champion et al., 2019; Chen et al., 2018; Jake-Schoffman et al., 2018).

Gamification was underexplored in the nutrition literature as part of the architecture of choice to change the nutritional quality of food choices of adults in online grocery shopping and adolescents in gadget-based nutrition interventions. Gamification uses game elements such as rules that participants should follow, point scoring and badges to motivate desired behavior outside of game settings (Deterding, 2012). In this thesis, I tested the use of game elements to improve the nutritional quality of the food bundle in the final shopping basket of American adults in The Grocery Store, a simulated online grocery store (Braga et al., under review), and the nutritional quality of the food consumption of female adolescents in Vietnam using FRANI, a phone application (Braga et al., 2021).

The Grocery Store had commonly sold products from American real grocery stores displayed from most to least sold and organized in ten major categories (Braga et al., under review). Food was classified and labeled according the Guiding Stars, a validated nutrient profile model consistent with the Dietary Guidelines for Americans and the Food and Drug Administration labeling policy (Guiding Stars, 2018). The Guiding Stars system has also been used by retailers such as Ahold Delhaize in online and brick-and-mortar stores in the United States (Braga et al., under review; Guiding Stars, 2018; Fischer et al., 2011; Sutherland et al., 2010). Healthy products received a positive number of points and unhealthy products received zero or negative points (Guiding Stars, 2018). We created a visual scale so that every food in the store displayed from one (lower Guiding Stars score) to five (higher Guiding Stars score) crowns (Braga et al., under review).

A pilot study and a larger experiment with similar design showed that American adults chose healthier foods in the presence of gamified nutrition labels based on a twelve-items shopping list (Braga et al., under review). Participants who saw the gamified version of The Grocery Store chose products with more crowns than

participants who did not see the game elements (Braga et al., under review). In the pilot study, the difference between the nutritional quality of the final shopping basket of participants in the gamified vs. non-gamified groups was almost as large as the difference between the groups that received $30 and $50 (Braga et al., under review). This suggests that gamification facilitates healthy food eating almost as much as receiving an additional $20 to purchase food. However, the budget was not significant to explain the quality of the final shopping basket in the larger experiment. The difference between the two studies were the sample size, the characteristics of the participants, and where the participants were recruited. Most of the participants from the pilot study were white/Caucasian, men and aged from 35 to 44 years, and were recruited in Amazon Mechanical Turk (Braga et al., under review). Almost half of the sample (n=654) showed signs of food insecurity such as often not having money for buying enough food, having to cut the size of meals and not being able to afford a healthy diet (Braga et al., under review). In the larger experiment (n=1,112), most participants were low- and middle-income females and from ethnic/racial minorities, of which 45.5% had college degrees and 20% were in food assistance programs such as the Supplemental Nutrition Assistance Program (SNAP) and Women, Infant and Children (WIC) (Braga et al., under review). The greatest effects of gamification were seen in the soups and sweet snacks, the list items of lower nutritional choice among the control groups (Braga et al., under review). The game elements may have raised awareness of the nutritional quality of foods, encouraging healthier food choices, or may have established a social norm based on the values of the nutrient profiling model of the Guiding Stars system (Braga et al., under review). The higher budget improved the nutritional quality of salty snacks, bakery, and rice, grains and pasta, but did not improve the overall quality of the shopping basket (Braga et al., under review). Gamification may benefit beneficiaries of food assistance programs as much as non-beneficiaries (Braga et al., under review).

Online grocery shopping is not common in low- and middle-income countries yet, but smartphones are increasingly common and could be a powerful tool to improve the dietary quality of adolescents (Braga et al., 2021; Braga et al., 2022). A pilot study in Vietnam showed that a gamified phone application could nudge adolescents to make healthier food choices using food image recognition, daily food consumption goals,

badges, statistics and notifications. The artificial intelligence built in the application recognized the images of the foods consumed in the pictures taken by the adolescents and linked them to food composition tables, which then computed the amount of each nutrient. Participants chose food consumption goals for food groups, for example “Eat dark green vegetables”. When food consumption goals were achieved, they won points and badges, and could share the achievements in a feed page with friends. Friends could send “hearts” when they saw others’ achievements. All the information of food consumption was summarized in a statistics page. There were three scores: My Goals, based on the food consumption goals chosen by the participants, the Dietary Diversity Score, based on the food groups of the Minimum Dietary Diversity for Women (Food and Agricultural Organization, 2016) and the Sustainable Healthy Diet Score, another name for the Eat-Lancet Diet Score (Knuppel et al., 2019). The My Goals were calculated according to the number of food groups consumed divided by the number of food consumption goals for a given day. The Dietary Diversity Score and the Sustainable Healthy Diet Score were fractions of the number of food groups eaten on a given day divided by the number of food groups of each indicator. Both scores were higher for the intervention group, that used the gamified version of the app, than for the control group, who had an application version limited to food image recognition and dietary assessment. Adolescents reported enjoying using the application, and there was high adherence to the study.

The evidence presented in this thesis suggests that gamified digital food environments were successful at influencing participants to make healthier decisions for food purchase and consumption. The context and populations of these studies were very different: The Grocery Store study recruited American adults, while the FRANI study recruited Vietnamese female adolescents. Both studies had strong designs, but the FRANI had a small sample size and all participants were from the same high school, which made the result less generalizable. Also, females tend to omit more unhealthy food consumption from researchers than the rest of the population. Adults, on the other hand, have more maturity to understand the consequences of omitting and lying for research results.

Moreover, we do not know if the healthier foods purchased in the Grocery Store, influenced by gamification, would be consumed in participants households. The improvement in the quality of food purchase not followed by changes in consumption would increase food waste. We also do not know if the improvement in the quality of food consumption of adolescents caused by gamified FRANI would influence the quality of foods purchased by them and their parents. A complete strategy to improve diets should integrate gamification of purchase and consumption of food. Future studies should divide people into groups who shop in gamified vs. not gamified online grocery store and use gamified vs. not gamified phone applications to understand their separate impact.

Critics have questioned the moral legitimacy of gamification in multiple contexts because it can cause harm to players unintentionally, recklessly, negligently, or inadvertently (e.g., Bogost, 2015; Kim 2015; Sicart 2015; Selinger, et al. 2015). Scoreboards, leaderboards, and competition can be taken as a stick or a carrot depending on the context and design (Anderson & Pildes, 2000). For example, a leaderboard system displayed on video screens for the housekeeping staff at Disneyland hotels in California resulted in considerable anxiety, embarrassment, and shame among workers (Lopez, 2011). The system, which workers nicknamed "the electronic whip," ranked employees' performance against their colleagues on a large screen. Some workers reportedly avoided taking bathroom breaks, while others became worried about losing their jobs (Lopez, 2011).

Scoreboards, leaderboards and competition were well received by the participants of the studies in The Grocery Store and FRANI, possibly because they felt it could help to achieve their personal goals (as opposed to the goals of their employers). But these elements may be applied in the future by real-life online grocery stores and nutrition-related phone applications without considering ethical issues. Gamification propels people in the same direction by communicating a narrow set of values through the point system, but the clarity of gamifying digital food environments may permit actors to alter the point system in their own favor. Companies should develop ethical frameworks for gamification that consider safety, security, privacy, transparency and accountability to avoid potential misuses, such as taking unfair advantage of consumers and workers (Kim & Werbach, 2016). Governments should regulate gamified environments quickly and

thoroughly based on adequate rational after identifying the individuals subject to gamification, considering their level of vulnerability, and the motivations of the organizations implementing it. In the case of online grocery stores and nutrition-related phone applications, validated nutrient profile models and indicators that maximize the dietary quality of the population should be used whenever point systems are used to influence purchases or consumption of food.

To play a game is to voluntarily take on unnecessary obstacles for the sake of the experience of struggling against them (Suits, 2014). However, should there be obstacles in gamified food environments? Would the obstacles keep individuals coming back for the sake of playing? Would people try to win the game in the sense of trying to achieve healthy diets? How long can people play a game for the sake of winning? Would struggles purposefully built for gamification of food environments to improve diets be unethical? Or worse, is gamification ethical at all? These are all important questions for further research.

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