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Evaluating augmented reality for 'real life' teaching of food portion concepts

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Abstract

Background: Estimation of food portions is a vital skill for dietitians, which is developed during formal nutrition training. Skill development is often accomplished by training with food portion estimation tools. These tools can vary in design but evaluations often reveal them to be limited in their effectiveness and generally impractical for everyday use. The aim of this study was to develop and evaluate an augmented reality (AR) tool for the estimation food portions.

Methods: An online, quasi-experimental, randomised pre-test post-test study was conducted to evaluate the effectiveness of three food portion tools with nutrition students. These tools consisted of an online, AR, and an infographic tool (control). Students tested 10 different food images and were asked to estimate food portion sizes with and without assistance of a portion tool to determine absolute error, relative error, and overall improvement in estimation.

Results: A total of 33 participants enrolled in the study with 26 (72.0%) completing the study. The mean absolute error was lowest in the online group (53.0%), followed by AR (59.5%) and control (64.0%). Relative error scores revealed higher accuracy for the AR group (45.5%) followed by online (43.5%), and control group (29.0%). Overall improvement in estimation was highest in the AR group (+12.2%) followed by the online (+11.6%) tool with a decrease seen for the infographic (−1.7%) tool.

Conclusions: The use of technology, notably AR technology, may provide some advantage when training nutrition students in food portion estimation, although further investigation is advised.

KEYWORDS

augmented reality, dietetics and nutrition training, food portion estimation, nutrition education

Key points

- Augmented reality technology may be useful in improving food portion estimation skills.
- The type and shape of food may increase the overall difficulty when estimating portion sizes.
- Number of years spent studying nutrition and dietetics may influence estimation accuracy.

INTRODUCTION

The portion sizes of prepackaged and restaurant meals have steadily increased over time, which can lead to an increased energy intake of as much as 35% per meal.[1–4] This can present a challenge to dietitians as they are often required to monitor their client's food intakes, and exposure to these larger portions can alter their perception of serving sizes. Although there are many methods that can assist a dietitian in helping clients to manage food intake, one of the primary techniques used is known as portion control.[5,6] To assist with this, it is important that dietitians are well trained in identifying portion sizes.

Portion control techniques are used by dietitians to advise and educate clients on selecting appropriate food portions at their meals.[7,8] This may be used for those who are underweight or malnourished and to assist with weight loss. The overall effectiveness of this dietetic skill relies on a specific subset of visual and spatial skills generally taught under the nomenclature of food portion estimation.

The fundamentals of food portion estimation include the ability to identify correctly the weight and volume of a wide range of foods by visual observation through the conceptualisation of food shapes.[9] Dietitians build on these skills during their formal education with the assistance of various food portion tools. These tools may include food image atlases, digital food models, food replica models, or training with different hand shapes to build the visual, conceptual, and memory skills that are required.[9–11] In studies which have assessed the effectiveness of these tools to increase food portion estimation accuracy, results have shown varying levels of success, with participants averaging 50–60% accuracy after training.[12,13] Increased difficulty is also reported when estimating amorphous foods such as cereal or pasta because of their irregular shapes.[14] Furthermore, many food portion tools have been perceived to be inaccessible or lacking in practicality as a result of their high costs or low portability.[13,15] Despite this, developments in technology have allowed for highly portable and visually engaging tools to be produced utilising virtual technologies such as augmented reality (AR).

The use of AR technology has become more common in recent years because of the ubiquitous natureof smartphone and tablet devices.[16] Recent studies have shown that these devices can be integrated successfully with AR technologies to create 'new' educational tools, which have been shown to significantly improve learning outcomes.[17–19] As the technology continues to improve, it brings with it the possibility for increased learning efficiency, portability, and accessibility, all of which can be used to create new and improved food portion tools. Furthermore, results from a recent survey indicate that dietitians tend to have a positive attitude towards the use of technology in their practice.[20] The aim of this study was, therefore, to develop and evaluate a new AR portion tool for nutrition students and to compare the accuracy of estimation against two other portion tools.

METHODS

Study design and recruitment

To assess the accuracy of the estimation food portions a quasi-experimental randomised pre-test, post-test study design was implemented (Figure 1). The study consisted of an online survey with questions designed to assess participant accuracy at baseline and following an intervention. The intervention contained a brief refresh of food portion estimation and provided access to a food portion tool. Participants were able to familiarise themselves with their assigned tool before reassessing their accuracy immediately after the intervention. All participants were randomised into either a control group or one of two technology groups. The technology groups included an AR tool and an online tool, while the control group received an infographic instructing them how to estimate food portions with different hand shapes. Images of hand shapes were determined to be an appropriate control as they are an accepted non-technology-based tool used in food portion estimation.[21] The control group also helped to account for confounding variables that are commonly seen in repeated measures studies such as history, maturation, and return to median.[22]

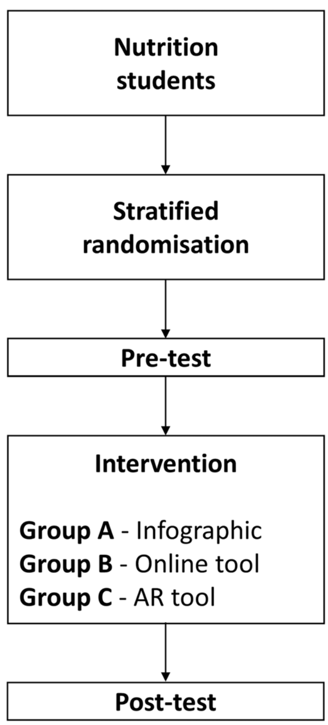

FIGURE 1 Conceptual framework of study design.

Students undertaking a nutrition degree at the University of Wollongong, attending the spring session of 2019, were recruited because of their relevance to the research topic. Recruitment occurred across all year levels. Stratified randomisation was used to ensure that an even number of male and female students across each year level were included in all arms. An a priori calculation was used to determine that a sample size of 21 students were needed per study arm (63 total) to ensure a power level of 80%. The researcher, independent of the dietetic teaching faculty, gave a brief presentation at lectures of nutrition subjects during the spring (second) session, during weeks 1–5 of 13, to inform the students about the study and encourage their participation. Students that wished to participate in the study were required to contact the researcher. Randomisation occurred after a cut-off period at the end of week 5 once all applicants had been screened, with the study commencing at week 6. Ethics approval for the study was granted by the University of Wollongong Human Research Ethics Committee (2016/022).

Online survey

An online survey was created using Survey Monkey (SurveyMonkeyInc., San Mateo, California, USA, www.surveymonkey.com). This consisted of 20 questions spread across two sections (post- and pre-test). Minor changes to the survey were implemented depending on how each group received access to their food portion tool. The access sections consisted of either a downloadable image, weblink, or a quick response (QR) code. Questions were designed to capture estimation accuracy, with an approximate completion time of 15–20 min. The survey underwent three iterations of validation (face, content, and construct) before a final version was disseminated for the study. This was to ensure that all questions and food images were free of confusion and easy to understand.

Portion estimation

Participants were asked to estimate the weight (in grams) of 10 different food images. The images (Table 1) consisted of two foods from each of the five food groups, with both solid and amorphous foods represented. Food images were sourced from a validated food image atlas with known portion sizes listed for each food.[23] The food image atlas was developed as part of a previous research project and, thus, participants had no access to or knowledge of the tool. Questions were ordered to ensure that each image contained a different food group from that of the previous question. The ordering of questions remained identical in both the pre- and post-test survey sections for consistency between the groups. Participants were also provided with a scale of the plate and bowl sizes presented in each image as a point of reference (Figure 2).

TABLE 1 Foods used in the portion estimation surveys (pre and post).

No.	Food image	Food group	True weight (g)	Display item
1	Cereal/cornflakes	Grains/cereals	30	Bowl
2	Green beans	Vegetables	140	Plate
3	Steak	Meat/poultry	130	Plate
4	Apple	Fruit	143	Plate
5	Cheese, sliced	Dairy	45	Plate
6	Cauliflower	Vegetables	132	Plate
7	Yogurt	Dairy	260	Bowl
8	Bananas, sliced	Fruit	157	Plate
9	Rice	Grains/cereals	190	Bowl
10	Fish	Meat/poultry	200	Plate

Note: Reference; Plate = 26 cm diameter, Bowl = 17.5 cm diameter.

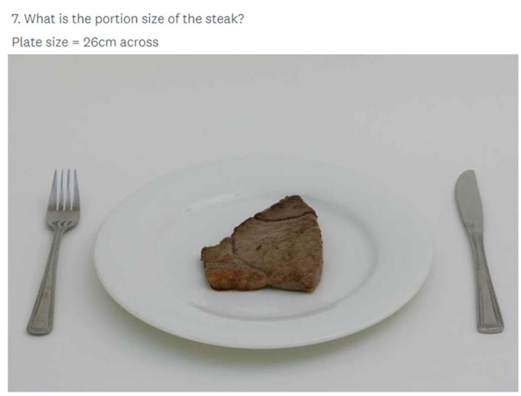

FIGURE 2 Example screenshot from online survey (steak).

Image quality

The original image quality for each food item had a dimension of 3504 × 2336 pixels and an average file size of 4.8 MB. Images were hosted on Google Drive (https://drive.google.com/drive/my-drive), where they were converted to 740 × 493 pixels to ensure that the survey images would load with speed whilst maintaining their clarity.

Food portion tools

Three food portion tools were examined. Each tool used a different type of technology ranging from a simple infographic to an interactive smartphone app.

Infographic

The infographic contained six sections instructing the participants how to estimate food portions using different hand shapes (Table 2). The graphic was embedded in the survey with a download link so that the participants could access the tool in the post-test. Images of different hand shapes (cupped, palm, fist) were used to convey a typical serving size along with the corresponding portion size. The infographic was created in line with the Australian Guide to Healthy Eating[24] to allow for calculation of the portion sizes displayed in the graphic.

Online tool

The online tool was designed as an interactive, web-based tool. Upon accessing the tool through a web browser, participants were shown a menu screen prompting them to select a food item. Once a food item was selected, an image of the food was loaded along with a list of options for interacting with the food. Participants had the ability to increase or decrease the portion sizes of each food and select three viewing angles. There was also an option to display the portion size of each food and compare each portion size to a reference image (tennis ball) which was shown to scale next to the selected food portion, providing additional visual assistance (Figure 3). A list of all the food types, portion sizes and plate sizes used can be seen in Table 3.

TABLE 2 List of food portion information included in the infographic tool (control group).

Hand shape = 1 serving	Food section	Portion information for One serving
Palm	Meat: beef, pork, lamb	65 g
Palm	Meat: chicken	80 g
Flat hand	Meat: fish	100 g
Cupped hand	Vegetables: nonstarchy	75 g
Cupped hand	Vegetables: starchy	75 g
Cupped hand	Grains/cereals: cereal	30 g
Cupped hand	Grains/cereals: rice	100 g
Cupped hand	Grains/cereals: pasta	50 g
Fist	Dairy: milk	250 ml
Fist	Dairy: yoghurt	200 g
Thumbs (×2)	Dairy: cheese	40 g
Fist	Fruit: berries, apples, apricots	150 g

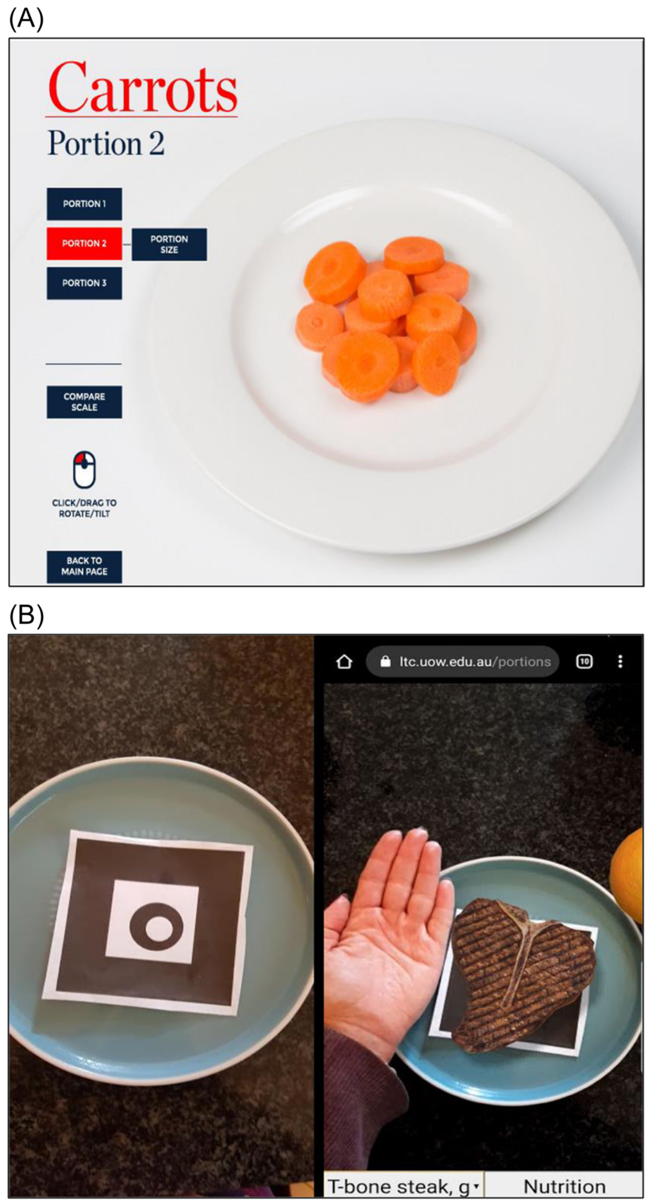

FIGURE 3 Example screenshots from two food portion tools. (a) Online tool, (b) augmented reality tool.

AR tool

The AR tool was designed to work as an app on the participants' smartphone device. To access the app, participants were given a QR code to scan with their smartphone. Participants were also required to download and print a fiducial marker. The fiducial marker consisted of a specialised printed pattern on 10 cm × 10 cm piece of paper, which, when scanned by the participants phone camera, would activate the mobile app. Brief instructions on how to use the app were provided in the survey.

The tool allowed participants to view virtual images of food overlayed onto real world environments on their

TABLE 3 List of foods and portion sizes available in online tool.

Food image	Food group	Portion sizes	Display item
Scotch fillet	Meat	71, 123, 176 g	Plate
Chicken (diced)	Meat	40, 80, 160, 200 g	Plate
Muesli (no milk)	Cereal/grains	30, 60, 90, 100 g	Bowl
Rice (white, long grain)	Cereal/grains	45, 90, 135, 220 g	Bowl
Milk (full fat, cow)	Dairy	100, 200, 250 ml	Glass
Cheese (tasty, pre-sliced)	Dairy	20,37,73,107 g	Plate
Banana (with peel)	Fruit	93, 165, 253 g	Plate
Apple (slices)	Fruit	37, 75, 150 g	Plate
Peas (baby)	Vegetables	13, 37, 75, 150 g	Plate
Carrots (slices)	Vegetables	37, 75, 150 g	Plate

Note: Reference; plate = 26 cm diameter; bowl = 17.5 cm diameter; glass = 6 cm diameter by 14 cm height.

TABLE 4 List of foods included in the AR app.

Food group	Food image	Portion sizes
Meat	Steak (T-bone, grilled)	180 g
Dairy	Cheese (gouda, wedge)	100 g
Grains/cereals	Rice (white)	120 g
Vegetables	Broccoli (small head of)	250 g
Fruit	Banana (medium)	98 g
Fruit	Apple (red delicious, medium)	164 g
Miscellaneous	Coffee (black, takeaway cup)	281 ml

smartphone screen at a 1:1 scale. Participants had the ability to zoom and rotate around the virtual image in the x, y and z planes by moving their smartphones around the fiducial marker.

Participants could use their hands as a point of reference on the screen if needed (Figure 3) and had the option to select from seven different food types. One portion for each food was available, with at least one food item from each food group represented (Table 4).

The AR tool was created as part of a collaborate program by University of Wollongong Learning and Teaching Centre. This was programmed as a smartphone app using javascriptlibraries (a-frame, ar.js, javascript edition 2019) run on either Android or iOS devices. Three-dimensional food model images were purchased from the turbosquid, sketchfab, and cgtrader websites.[25–32] Food models were edited in Blender software[33] before being exported to the app. The total number of foods available was lower than the other tools owing to limited resources availability at the time. Portion sizes of the images were determined by visual inspection and nutrient data was calculated using Food-Works software (Xyris software Australia Pty Ltd) using the AUSNUT 2011–13 food composition database.[34] The fiducial marker wascreated with the Blender software AR tool kit.[33]

Data collection and analysis

The survey data was extracted from Survey Monkey and imported into an XLS file for data management and analysis (Microsoft Excel, 2019, version 16.0.6742.2048). The estimation accuracy for pre- and post-test results were calculated using: $accuracy = (\text{estimation} - \text{true weight})/(\text{true weight}) \times 100$, providing the total level of error expressed as a percentage. Improvement in the estimation accuracy was calculated as the difference between the post-estimation error and pre-estimation error scores. The measured level of relative error was found to vary between studies, and so this study used an amalgamation of relative error rates used by studies with a similar a design.[35,36] This consisted of estimates within ±50% and ±25%[35–37] of the true weight. All data were statistically analysed using SPSS software (IBM Corp, Released 2012, SPSS Statistics for Windows, Version 21.0). Normality was assessed with a Shapiro–Wilk test. Where data met assumptions of the Levene test for homogeneity of variances, a one-way analysis of variance (ANOVA) was conducted with a post-hoc Bonferroni adjustment. All non-parametric data was assessed with a Kruskal–Wallis one-way ANOVA.

RESULTS

Participants

There were 33 participants recruited (11 in each group) and of these, 78.7% (n = 28) attempted the survey, with 72.7% (n = 26) completing both the pre- and post-test sections of the study. The final totals consisted of eight, ten, and eight participants in the control, online, and AR groups, respectively. Participants were predominately female (88% n = 23) ranging from 18 to 24 years with a mean of 2.2 (SD 0.89) years of study. Owing to the number of withdrawals in the study (n = 6), the spread of participants per group varied.

Absolute error

Analysis with a one-way ANOVA (pre-test) revealed that there were no significant differences in the pre-test estimation scores for the intervention and control groups, signifying that the mean level of accuracy at the pre-test was similar across all groups. The average error rates were 64%, 59%, and 53% for the control, AR, and online groups, respectively. Further analysis with a one-way ANOVA (post-test) revealed a significant difference in the absolute error rate between the groups for certain food types. These were, steak (p = 0.037), and fish (p = 0.013) for the AR group, with green beans (p = 0.018) and rice (p = 0.017) for the online group, when compared with the control group. No significant differences were found for the absolute error when adjusting for participant year level, age, or gender. The average absolute estimation error percentages for each food item and group can be seen in Table 5.

TABLE 5 Average estimation error (absolute) of foods by intervention group and year level.

Average estimation error per food item by experiment group (%)			
Food	Control (n = 8)	Online (n = 10)	AR (n = 8)
Cereal	152.0	226.6	233.3
Beans	50.8	14.6	40.5
Steak	33.3	25.4	21.8
Apple	45.5	29.6	10.9
Cheese	48.1	38.8	114.8
Cauliflower	54.9	49.3	31.4
Yogurt	45.5	25.0	24.3
Bananas (sliced)	71.6	61.8	55.4
Rice	65.2	15.8	31.5
Fish	65.7	43.1	31.0
Mean error	64.1	52.9	59.5
Average estimation error per food item by year level (%)			
Food	**First year (n = 7)**	**Second year (n = 4)**	**Third year (n = 15)**
Cereal	245.1	272.7	196.8
Beans	48.5	51.8	27.7
Steak	43.7	40.9	25.2
Apple	40.5	57.8	23.4
Cheese	56.3	60.9	54.3
Cauliflower	56.4	48.2	45.3
Yogurt	34.4	36.3	32.1
Bananas (sliced)	73.9	44.5	58.2
Rice	39.7	38.8	26.8
Fish	47.5	36.9	34.7
Mean error	68.6	68.9	52.5

Relative error

Relative error refers to the percentage of estimations that fell within ±50% and ±25% of the true weight of food. The mean scores were similar across all groups at the pre-test with one-way ANOVA showing no significant differences. The post-test scores revealed that 45.5% and 43.5% of estimations fell within the test ranges for the AR and online groups, respectively, while the control group recorded 28.9% of all estimations within the relative error margins (Figure 4). When adjusting for participant year level, accuracy was seen to increase by year level, with 28.0%, 30.0%, and 49.5% of scores within assigned error margins for first, second, and third year, respectively.

Improvement of estimation accuracy

Improvements in the accuracy of estimation varied between the intervention and control groups. Positive scores were recorded in the AR and online groups with a +12.2% and +11.6% increase, respectively. This contrasted with the control group, which recorded a negative improvement rate of −1.7% (Figure 5). When investigated by year level, the mean improvement was found to vary. Participants in second year recorded the greatest improvement at 35%, followed by third year at 3.5%, while first year participants recorded a negative improvement of −1.5% irrespective of group.

DISCUSSION

This study compared three different portion tools for the estimation accuracy outcomes of nutrition students. Participants in the AR and online tool groups had a greater overall accuracy in estimating food portions when compared with the control group.

Food portion estimation studies are known to contain highly variable outcomes when assessing the accuracy of estimation as the estimations can be either over or under the true weight of a food.[38] In this study, relative error measurement was used to account for this variability, taking all estimations into consideration. Overall, the AR group was shown to have the highest level of accuracy when assessing relative error with 2% greater accuracy than the online group and 16.6% greater accuracy than the control group. These results partly align with similar studies,[35,36] which found a greater level of estimation accuracy when using an AR technology. However, the level of accuracy reported in these studies was substantially higher. The results from this study may have been affected by a number of factors, such as the wider variety of portion sizes and types of foods used, and the use of food images for making the estimations as

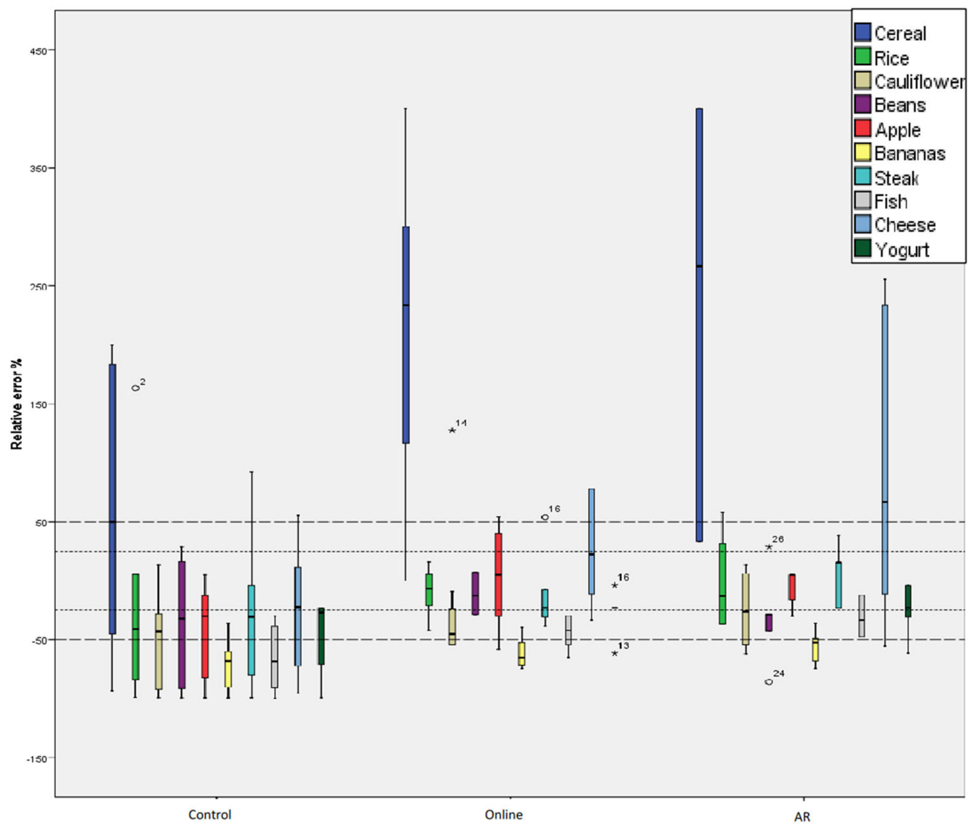

FIGURE 4 Relative error levels between study groups showing 0%, ±25%, and ±50% error.

opposed to estimating with 'real' food portions in person.

Participants were required to make estimations against images of food instead of real foods, which is less common in evaluation studies. Estimating from images instead of from real foods could increase the difficulty, as some studies have found mixed results when using this technique.[13,39,40] Furthermore, participants also estimated a wider range of foods at varying portion sizes, whereas comparative studies either required participants to estimate a single serving of one food group[33] or to make estimations on only one food type.[34] In addition, the shape and size of the food being estimated is known to have an impact on the overall accuracy, with previous studies revealing that smaller, irregular shaped foods can produce higher rates of error.[10,14,40,41] This trend was generally observed when assessing the average error rates for foods across groups, however, the level of error between amorphous and solid foods was shown to vary, especially in the AR group. The level of variability seen in the AR group was somewhat comparable to two previous studies,[35,37] which also found mixed results across different food types when using an AR food portion tool. Overall, difficulty with certain foods was shown to have a significant impact on accuracy of the results. This was especially apparent for breakfast cereal, which had an average error rate of +268.5% across each tool and was the most over-estimated food type. The high level of error may have been resulted from the complexity of cereal as it consists of small irregular shapes with multiple units, which have been found to increase difficulty with estimation of food portions.[38,42] This may also explain the high error for banana slices (62.9%) but did not account for the high error rate seen for cheese, which was only observed in the AR group at 114.8%. It is possible that the image used for cheese in the AR tool (wedge) was not suitable for training when compared with more common images, such as cheese slices.

The improvement in accuracy between the pre-test and post-test scores was highest in the AR group followed by the online group, while the control group showed decreased accuracy. The improvements could not be directly compared with other food portion estimation studies as they had either not assessed or had not used the same food portion technology. However, when comparing against food portion estimation studies using older technologies,[15,43,44] both the AR and online groups showed greater improvement (by an average of 7.8%). This may be due to both technologies providing an enhanced level of visual information when compared with older methods, such as the use of hand shapes. These outcomes suggest that the AR and online tools may be more effective for improving accuracy with short-term training.

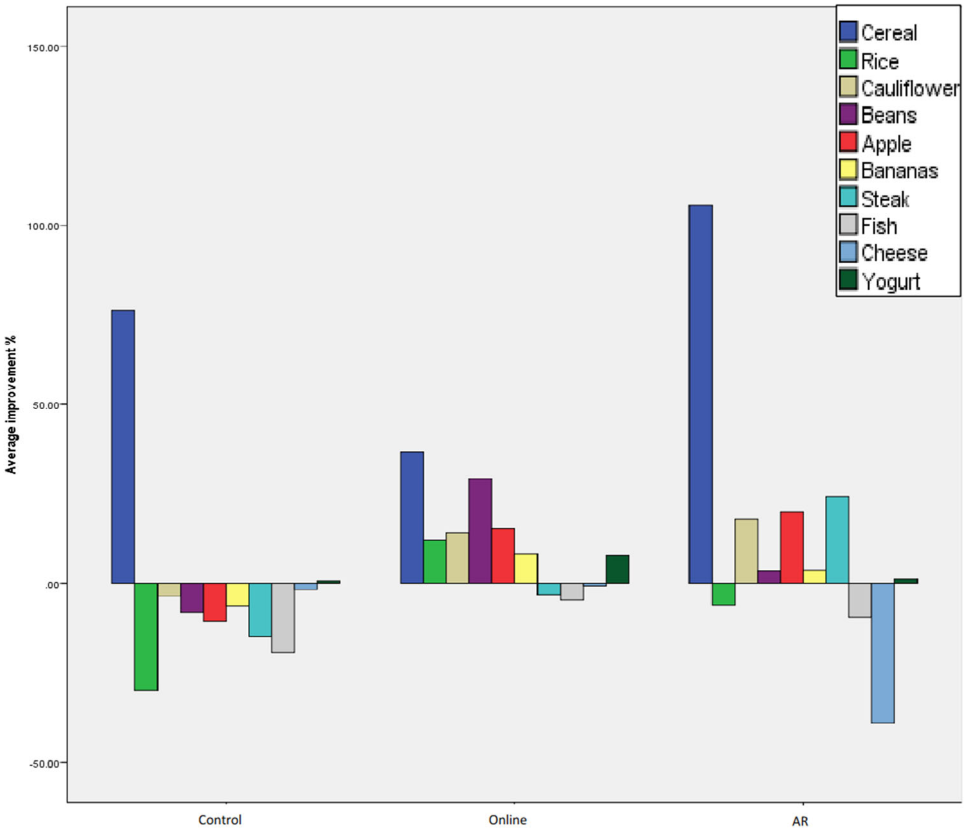

FIGURE 5 The overall level of improvement in each food type between groups as a percentage.

The spread of participants was noted as an important confounding variable at the beginning of the study and care was taken to ensure an even distribution of first, second, and third year participants into each study group using stratified randomisation. This was to account for any differences in learning experience. When controlling for accuracy outcomes by subject year, there was a noticeable difference in overall performance between participants and year of study. First-year participants had the lowest scores while second-year participants recorded the highest ratings across all domains, followed by the third-year participants with moderate improvements. The variation in first-year participants may have resulted from an overall lack of experience and exposure to portion estimation techniques while the differences between second and third year may have resulted from the low sample size in second-year participants. Despite the low sample size, study groups were relatively even, with the exception of the AR group, which did not contain second-year participants owing to dropout. Furthermore, the distribution of first-year participants was relatively even across the groups, suggesting that the overall accuracywas not significantly impacted by the participants' year of study.

There were several limitations noted when assessing the outcomes. First, the sample size affected the overall power and strength of results and the use of food images may have increased the difficulty by comparison with the use of real foods. The study was also conducted in the participants' own time, which meant that it was not possible to know if other tools were used by the participants, although the similar pre-test scores indicate that this may not have been the case. In addition, the type of food images used across three tools differed as it was not possible to use the same images owing to formatting restrictions. This meant that it was possible that some images may have been more effective than others regardless of the tool used. The AR tool also lacked functionality, such as portion scaling and a larger selection of food items, which may be added in future versions of the app. Lastly, this study did not assess the effectiveness of the AR tool in patient populations which would require further investigation.

CONCLUSION

This study investigated the accuracy of three different food portion tools. The findings suggest that both the AR and online tools may provide a more effective method for the training of student food portion estimation skills when compared with the use of traditional hand shapes. The AR and online tools were generally comparable in all areas of evaluation.

Continued development of the technologies may be beneficial for improving food portion estimation skills in nutrition students and further evaluation is recommended.

AUTHOR CONTRIBUTIONS

Ioannis Mellos: conceptualization (equal); data curation (lead); formal analysis (lead); investigation (lead); methodology (lead); project administration (lead); resources (supporting); software (equal); validation (equal); visualization (lead); writing–original draft preparation (lead); writing–review & editing (lead). **Yasmine Probst:** conceptualization (equal); data curation (supporting); formal analysis (supporting); investigation (supporting); methodology (supporting); project administration (supporting); resources (lead); software (equal); supervision (lead); validation (supporting); visualization (supporting); writing–original draft preparation (supporting); writing–review and editing (supporting).

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CONFLICTS OF INTEREST

The authors have declared no conlficts of interest.

TRANSPARENCY DECLARATION

The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported. This research involved the use of an online survey with ethics approval. The lead author confirms that no important aspects of the study have been omitted and that any discrepancies from the study as planned have been explained.

ETHICS STATEMENT

University of Wollongong Human Research Ethics Committee, approval number 2016/022.

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