Managing obesity through mobile phone applications: a state of the art review from a user-centred design perspective

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Evidence has shown that the trend of increasing obesity rates has continued in the last decade. Mobile phone applications, benefiting from their ubiquity, have been increasingly used to address this issue. In order to increase the applications' acceptance and success, a design and development process that focuses on users, such as User-Centred Design, is necessary. This paper reviews reported studies that concern the design and development of mobile phone applications to prevent obesity, and analyses them from a User-Centred Design perspective. Based on the review results, strengths and weaknesses of the existing studies were identified. Identified strengths included: evidence of the inclusion of multidisciplinary skills and perspectives; user involvement in studies; and the adoption of iterative design practices. Weaknesses included the lack of specificity in the selection of end-users and inconsistent evaluation protocols. The review was concluded by outlining issues and research areas that need to be addressed in the future, including: greater understanding of the effectiveness of sharing data between peers; privacy; and guidelines for designing for behavioural change through mobile phone applications.

Keywords: obesity, user-centred design, mobile phone, ubiquitous

Recent evidence shows that the worldwide obesity rate is increasing and has more than doubled since 1980 [1]. The latest data from the Centres for Disease Control and Prevention (CDC) showed that more than one third of US adults were obese, with adults aged 60 and over more likely to be obese than younger adults [2]. Similar trends have been reported in Europe, where between 30% and 80% of adults are obese with higher prevalence of obesity among men than women [3]. Obesity and being overweight have considerable effects on morbidity and mortality through various diseases such as type-2 diabetes, cardiovascular diseases and metabolic syndrome [3]. Obesity yields negative economic consequences as a result from direct costs (increased medical costs to treat the associated diseases), indirect costs (lost productivity due to absenteeism or premature death) and intangible costs (psychological problems and poorer quality of life). Fry and Finley [4] revealed that the total direct and indirect cost for the 15 countries that were European Union members before May

2003 were estimated to be €32.8 billion per year, while for United States the estimated cost was US$147 billion [5]. Nagai et al. [6] reported that in spite of shorter life expectancy, individuals that are obese still require higher lifetime medical expenditures than those of normal weight. These costs are likely to increase as the prevalence of obesity increases [7]. The above factors have prompted initiatives to prevent obesity which range from the implementation of public health policies such as nutrition labeling [8], unhealthy food and drinks tax [9], to interventions by means of mobile phone applications to promote healthy eating and increased physical activity [10]. Some literature reviews, which have studied the effectiveness of obesity prevention through mobile phone applications, reported a mixed outcome of the intervention effectiveness [11, 12]. Although these reviews suggest possible factors that contributed to this phenomenon, none of them looked into the design process of these applications and how it might affect their successful adoption by the target users. It has been widely acknowledged through a variety of studies that failure in understanding users during design and development of any product or system can results in a low acceptance and effectiveness [13]. One approach to ensuring successful product or system design is the application of User Centred-Design (UCD), first introduced by Norman and Draper [14]. UCD refers to how end-users influence a design through their involvement in the design processes and has been shown to contribute to the acceptance and success of products [15]. This paper presents a review of the extent to which the design processes of existing mobile phone applications to prevent obesity have incorporated the principles of UCD. Our objectives were: i) to identify key principles of UCD that were applied to develop existing mobile applications to obesity prevention; ii) to analyse the strength and weakness of their design approaches and processes; and iii) to identify any gaps in the research and propose future directions.

This paper begins by describing UCD in detail and is followed by explanation on how studies that were included in the review were identified and analysed. Next, the results of the review are explained in detail. The last two sections of the paper discuss the strengths and weaknesses of the reviewed studies and emerging issues and future research questions that need to be addressed to advance our understanding. This paper's main contribution lies in the identification of gaps within this research area from a UCD viewpoint and how to address these gaps through recommendations for future research.

User-Centred Design

UCD is a common term, encompassing a philosophy and variety of methods, which refers to how end-users influence a design through their involvement in the design process. The level of user involvement in UCD varies and can range from a simple observation of end users in their working environment to including user representatives on the design team. Key principles associated with UCD (ISO 9241-210:2010) are described as follows:

- Clear understanding of users, tasks and environments. Explicit understanding of the characteristics of users, tasks and environments enables identification of the context in which a system will be used by users. This context of use subsequently assists in establishing users' and/or organisations' requirements and relevant usability goals. Approaches such as stakeholder identification and analysis, field study, user observation and task analysis can be adopted to gain an understanding of users, tasks and environments [16].
- User involvement throughout design and development. Active user involvement should be upheld throughout the design and development process of a system. This could be achieved through various ways, such as including end-users or their representatives in a design team, consulting potential end-users and relevant stakeholders to assist requirements gathering and involving end-users in usability testing [17].
- Driving and refining design through user–centred evaluation. This key principle emphasises the importance of user-centred evaluation to inform a design and to improve it at all stages. Typical activities include presenting low or high prototyping and storyboarding to potential end-users, post-experience interviews and satisfaction questionnaires of preliminaries design, etc. [18].
- Iterative design process. Making the design process iterative is a way of ensuring that users can get involved in the design and that different kinds of knowledge and expertise can be brought into play as needed [15]. Iterative design processes can be identified through integration of the formative evaluation outcome into later or final designs.
- Addressing the whole user experience. This key principle emphasises how a design should also consider the quality of a user's experiences while interacting with a specific design and not focus solely on usability i.e. whether or not a design is

effective and efficient. In other words, a design should promote positive emotions and feelings to users while interacting with it [19]. Attempts to address user experience can be identified through the use of interviews and/or distribution of questionnaires which probe end users' experiences after using a system.

- Inclusion of multidisciplinary skills and perspectives. A range of views, including those of non-technical specialist experts, end users, relevant stakeholders, etc. is required during the design and development of a system [15]. This could take the form of a consultation with and/or inclusion of these people in a design team.

Methods

The articles included in this review were primarily identified from a meta-search on engineering databases which included ANTE, ACM DL, Ei Compendex, IEEE Wiley eBooks Library, IEEE/IET Electronic Library, INSPEC (Ovid), INSPEC Archive (Ovid) and Zetoc. The search was limited to English-language communications in peer-reviewed journals, conferences and books that were published between 2000 and 2012. Only articles that reported the utilisation of mobile phones to promote healthy eating and physical activity were included in the review. The following terms: "obesity phone", "physical activity" and "phone" and "obesity", "weight loss" and "phone", were used to perform the search. As this review focuses on obesity, articles that reported the use of mobile phone applications for other purposes e.g. diabetes patient monitoring, rehabilitation, wellness monitoring for elderly, etc. were not included in the review. Furthermore, articles which focused on sensing devices and their mechanisms, or were limited to blue prints/concepts of mobile phone applications to prevent obesity, were also excluded from the review.

For each study, we asked the following questions: 1) "How is the created mobile phone application used to prevent obesity?"; 2) "What key principles of UCD were adopted during its design and development process and how were they applied?"; 3) "Was the mobile phone application effective and what measures were used to determine its success?". For the second question, design and research activities that were relevant for each key criterion were identified. It is acknowledged that the outcome of the assessment was largely affected by how much detail of the design and research activities were reported or published. To minimise the effects of this issue, all publications related to a website or mobile phone application were tracked and included in the review. For the third question, only studies that reported deployment of their applications to users in real-life situation were reviewed.

The review method adopted in this paper is largely based on research literature from scientific publications and does not survey the many commercial mobile-phone applications that have been developed in recent years. One reason for this decision is that, unlike for research literature, there is no systematic way to get a comprehensive overview of commercial products. The other reason is that our goal was to provide an overview of the design and development process of mobile phone applications and this information is not likely to be easily accessible in the commercially sensitive private sector.

Results

Figure 1 provides a flow chart documenting the results of the study selection process which resulted in the inclusion of 52 mobile phone applications in this review. As the review was based only on scientific publications and excluded those that are available commercially, it has to be noted that the list of the mobile applications for obesity prevention is not necessarily exhaustive.

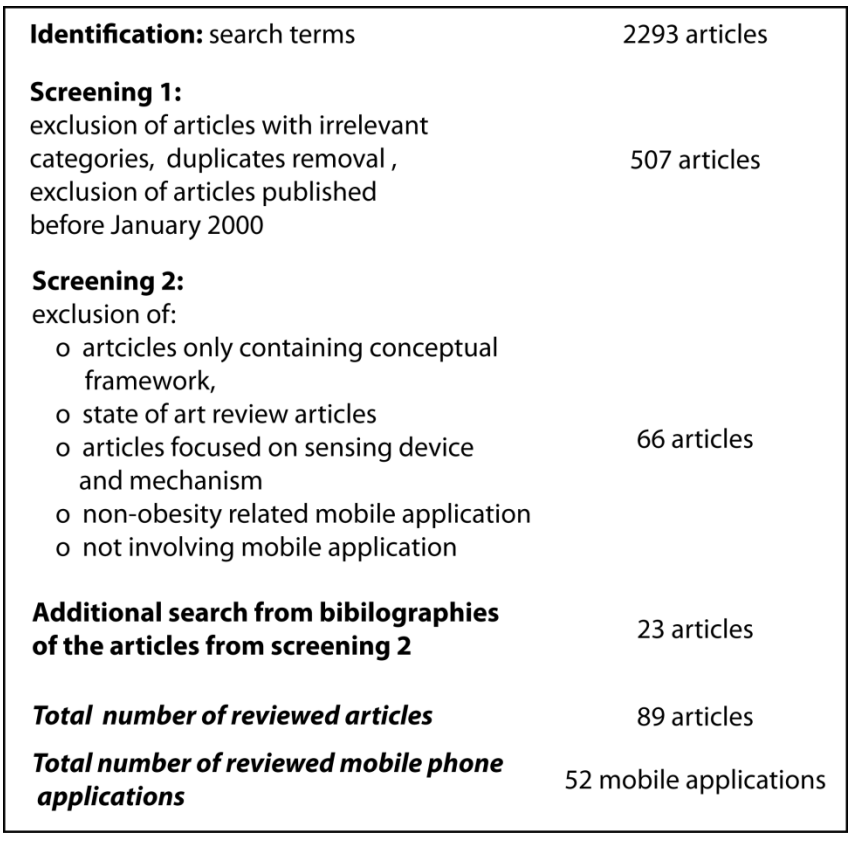

Figure 1. Search results

An overview of the mobile applications included in the review is shown in Appendix A. A quick glance on this suggested that more than half of the applications design (33 articles – 63.5%) did not incorporate theories or principles that could encourage behavioural changes, despite aiming to do so. Although incorporation of relevant theories into applications does not necessarily guarantee the success of applications in inducing changes of behaviour, there is a strong likelihood that such a system would likely be more capable in achieving this through design. For instance, in Mobile Snack, Khan et al. [63] incorporated the Transportation Theories [112, 13] and Precaution Adoption Process Model [114] by providing an immersive animation-based narrative that depicted the game characters' progressive life stages based on their eating behaviour. They also applied Social Cognitive Theory [115] by allowing users to view their eating behaviour history and compare themselves with other users. The overview results also suggested that only a minority of the reviewed studies defined the specific end-users for whom their applications were targeted and instead opted for a broad definition of end-users e.g. individuals with obesity or overweight issues, individuals with sedentary lifestyle. Having such a broad definition of users will potentially result in overlooking some users and limit the applications' effectiveness. For instance, users of UbiFit, a tracking application which provided feedback on users' physical activity level through a garden metaphor on its glanceable display, preferred to have metaphors for displays that suited their interests [97, 98]. A similar thing was also experienced by users of Neat-O, a game application that motivates its users to compete against each other based on their physical activity level and rewards them with choice of mini games. In this instance users suggested adjustments on the type of mini games provided based on age groups as well as pop-up motivational statements appropriate for different gender [73].

This paper revealed that mobile phone applications to prevent obesity can be grouped into four categories. These were: a tracking assistant (assisting a user in tracking and reviewing his/her behaviour), an entertainment tool (persuading a user to adopt an intended behaviour through game), an advisory assistant (advising a user to adopt an intended behaviour), and a tool to leverage social influence (providing a platform for a user to interact with his/her peers to encourage adoption of an intended behaviour). Figure 2 shows the proportion of mobile phone applications in each category. The lower proportion of mobile phone application's role as advisory and enforcement of social influence is likely due to the recent availability of mobile social network platforms and GPS technologies. As such, smart phone applications in

these categories are expected to grow in numbers in the future. It is also expected that social network platforms and GPS technologies will be important part of future applications of the first two categories.

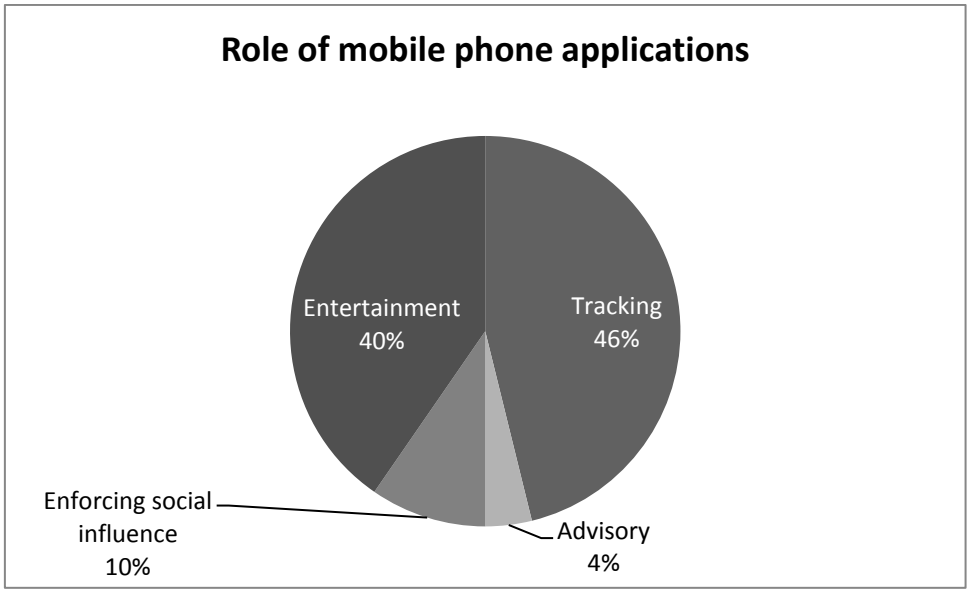

Figure 2. Four categories of mobile phone application's role to prevent obesity

A further examination revealed that the majority of the reviewed studies produced fully functioning prototypes (see Appendix B for a review of the mobile phone applications from a UCD perspective). Unfortunately, it also appears that these prototypes were not necessarily developed based on a thorough understanding of users or how and when they would use these applications. Only 30.8% of the reviewed studies indicated any design activities that involved either targeted users or relevant stakeholders prior to the design of applications. Incidentally, although the majority of the reviewed studies (88.5%) either performed or at least planned an evaluation study that involved end-users, only less than half of the reviewed studies (42%) demonstrated that the application designs were refined through user-centred evaluation prior to the development of fully functioning prototypes. Furthermore, only 46% of the reviewed studies indicated the existence of an iterative design process. All of the above findings indicate that user-centred design principles were not fully adopted by researchers while designing existing mobile phone applications. These findings also suggest that the design for the functions and features of the applications were driven in the majority by perceptions of the application designers on users' needs and requirements. Coupled with the fact that these studies adopted a broad definition of end-users, there is a strong likelihood

that the end product is a mismatch for the targeted end-users. Unfortunately, it was not possible to identify from the reviewed paper what might cause this phenomenon. Vredenburg et al. [18] emphasised the importance of user involvement to support understanding of user and iterative development throughout the design and development of a system. During the early stage, user involvement is valuable to provide support for design decisions as well as problem detections of a system; while at a later stage it can help to verify the quality of a system. Failure to provide adequate user involvement means that changes at later stages are likely to occur and be more costly or difficult to be accommodated. For instance, Buttusi and Chitaro [64], who designed Monster and Gold game application, discovered only after user evaluation that their application could be repetitive if used several times due to lack of game setting varieties. Another example is Fukuoka et al. [70], who designed mPED that sent daily messages to suggest context-aware physical activity, overlooked the users' need for personalisation and variation of encouraging messages and only discovered at a late stage some of their end-users considered found this to be source of disappointment.

Most of the reviewed studies (63.5%) addressed the whole user-experiences while evaluating their functioning prototypes. This finding suggests that designers acknowledged the importance of assessing user experience, especially when long term engagement is required. All of the reviewed studies conducted interviews to investigate user experience. Although interviews enable an in-depth understanding, they present a challenge for comparison studies. Using a set of established questionnaires, such as AttrakDiff [116] is expected to resolve this issue. Last but not least, it was found that most of the reviewed studies (73%) indicated the inclusion of multidisciplinary skills and perspectives during their application design and development. This proportion is high as various aspects such as the presence of underlying behavioural change theories, consultation with experts/users and inclusion of experts/users in the design team, were used as indicators.

Table 1 shows the evaluation results of the reviewed studies which produced fully functioning prototypes and which were deployed to users for more than one day. Out of the 52 studies, only 14 (27%) conducted field studies with their targeted end-users, with deployment of the applications ranging from one day to three months. This finding suggests that, at the moment, most of the research effort was concentrated on the development of the applications and lack of attention was paid to investigate their effectiveness. It is possible that this phenomenon occurred due to the continuous and fast-paced technological development related to mobile phones which consequently encourages more research to

investigate the latest technology utilisation and leaves little time to study its effectiveness. For instance, based on the reviewed paper, the incorporation of a mobile phone's camera to assist automatic recording of food intake was only initiated in 2008 and as the time progressed, the complexity of technology used also increased i.e. from simply using a camera [45, 46; 91-93), to video camera [39] and a combination of a video camera and laser generated grid [37, 38].

The review showed that nearly all of the studies collected qualitative data (related to usability and/or user experiences) and quantitative data simultaneously. The type of quantitative measurements that were collected by most of the studies differed from one study to another although all of them aimed to capture how their applications prompted behavioural changes. As a result, performing comparison of effectiveness between applications will likely be difficult if not impossible. Furthermore, taking into account that most of the applications were aimed at preventing obesity, it was quite surprising that only a few of the reviewed studies used weight change as one of their quantitative evaluation measurements. It is acknowledged that, as some of the studies only focused on one particular thing (either physical activity or eating behaviour), changes in weight do not provide an independent measure as it is affected by both physical activity and eating behaviour. With regards to the results of the evaluation, it is clear that more research is needed to provide firm evidence on the effectiveness of mobile phone applications to prevent obesity. All of the 14 reviewed studies suggested that mobile phone applications have the potential to encourage change of behaviour to prevent obesity. However, it is difficult to ascertain if the observed potential will be sustained on a long-term basis since only 2 studies out of 14 studies deployed their applications for 3 months. A similar problem has been experienced in establishing the effectiveness of internet-based and video game to combat obesity [117-119]. Mattila et al. [108] even suggested that mobile phone applications will not be effective unless they are part of an intervention which "provides the initial motivation and engagement that enable users to reach the "long-term" stage".

Table 1. An overview of the evaluation of mobile phone applications included in the review

		How was it evaluated?	Qualitative measures	Quantitative measures	Outcome
1.	**Chick Clique [20, 31]**	Deployment of the application for 2 weeks (n=8 participants)	Usability and user experience	Number of steps	Increased number of steps compared to baseline.
2.	**DiaTrace [34, 35]**	Deployment of the application for 1-4 days as part of a structured treatment and teaching programme (STTP) for weight reduction (n=124 participants)	*Not indicated*	Discrepancies of physical activities and calorie intake between manual self report and Dia-Trace	Self reported calorie intake was slightly lower than the objective energy intake and vice versa for physical activities.
3.	**Houston [51, 52]**	Deployment of the application for 3 weeks (n=13 participants)	User experience	Goal achievement (number of steps)	Participants that shared their achievement in groups performed better than those that did not.
4.	**HyperFit [53]**	Deployment of the application to a group counseling members (n = 39 participants) for 2-3 days	User experience	*Not indicated*	*Not indicated*
5.	**Impact [56]**	Deployment of the application for 8 weeks (n=49 participants)	Usability and user experience	Steps count, awareness of physical activities and awareness of opportunities for	Automated tracking of physical activity and contextual information benefited long-term reflection, but might have detriment effects on

				physical activities	immediate awareness
6.	**Into [57]**	Deployment of the application for 1 week (n=37 participants)	Usability and user experience	*Not indicated*	Virtual trip analogy was understandable, concrete and interesting for users; but familiarity should also be considered.
7.	**Motivate [67, 68]**	Deployment of the application for 5 weeks (n = 25 participants)	Usability	Number of responses to context aware physical activities suggestion	Higher compliance for simple daily activities.
8.	**NEAT-o-Games [72-74]**	Deployment of the application for 4 weeks (n = 10 participants)	Usability and user experience	Frequency of use	7 participants' used the application at least 50% of the time studied.
9.	**OrderUp [75, 76]**	Deployment of the application for 3 weeks (n = 12 participants)	User experience	Frequency of use	6 participants reported multiple uses per day.
10.	**PmEB [79, 80]**	Deployment of the application for 1 month	Usability and user experience	Compliance of data entry for daily calorie consumption and expenditure	Higher compliance compared to paper form.
11.	**Time to eat [94, 95]**	Deployment of the application for 1 month (n=39 participants)	User experience	Frequency of skipping breakfast	Participants with a virtual pet that exhibited both positive and negative expressions were twice as likely to

					eat breakfast.
12.	**UbiFit [97-101]**	Deployment of the application for 3 months (n=28 participants)	Usability and user experience	Physical activity duration	Physical activity of participants without glance able display decreased over time.
13.	**Weight Management Mentor [103, 104]**	Deployment of the application for 8 weeks (n=56 participants)	*Not indicated*	Weight loss and engagement with the application (active days, user activities, and info accesses)	Higher weight lost in both supportive and unsupportive intervention. Users engaged more with an interactive application (by means of prompting).
14.	**Wellness Diary [105-108]**	Deployment of the application for 12 weeks as part of an intervention studies (n = 47 participants) and 2 weeks for independent use (n=16 participants)	Usability and user experience	Frequency of use, weight change	WD worked when used as part of an intervention setting.

Strengths and weaknesses of existing studies from UCD perspective

Based on the results of the review in section 3, the strengths and weaknesses of existing studies from a UCD perspective were identified (see Table 2). Current studies have, to some extent, included multidisciplinary skills and perspectives through consulting and/or involving users early in the design and/or evaluation stage. However, there are limitations to the involvement of users as users' knowledge of behavioural change domain and awareness of their own needs may be limited [120, 121]. Therefore, more effort should be made to incorporate relevant behavioural changes theories into the design and development of mobile phone applications. A similar analogy to this is a creation of a virtual training system in which the training system's content and delivery should still be based on training principles while its interface design and context of use are consulted with end-users or relevant stakeholders. As mentioned earlier, there is some evidence that users were involved during the development of mobile phone applications. However, most of the involvement occurred only in the formative evaluation with few, if any, taking place prior to this. Frequent end-user involvement could be impractical and costly as could performing major changes post formative evaluation. Therefore, a design team should weigh the benefit and cost of each circumstance at the beginning of the project and use this judgement to make their decisions. The review also showed that iterative design practices were widely adopted across studies. However, the level of iterative design process varied between studies, with some studies only using the results of formative evaluation to improve their application design. Again, the same judgement made for user involvement explained above also applies. It should be noted that iterative design practices do not necessarily equate to higher level of user involvement in the design as the iteration could simply be triggered through less formal evaluation such as heuristic evaluation [122] or cognitive walkthrough [123].

Table 2. Strengths and weaknesses of existing studies from UCD perspective

Strengths	Weaknesses
Inclusion of multidisciplinary skills and perspective	Broad specification of end-users
Some evidence of user involvement	Effectiveness evaluation
Some evidence of Iterative design	

practices	• Lack of reference to theories or principles of behavioural change • User studies too short to adequately monitor effectiveness of change • Inconsistent evaluation protocols reduce ability to compare effectiveness of different applications

Some weaknesses of existing studies were also identified through the review. The most commonly noted is the lack of focus on specifying target end-users. Obtaining a full understanding of users will likely be a challenge if end-users are not fully specified from the beginning. This could result in the inability to thoroughly identify what they want from a design, how and when they will use it, what makes them want to use it, etc. There is strong evidence that behavioural change needs to be tailored to match an individual's needs and characteristics in order to be effective and sustainable [124, 125]. Furthermore, by providing specific target end-users from the beginning, relevant stakeholders could be identified and potentially involved. A perfect example of this is a study by Toscos et al.[31], who having specified their targeted end-users as teenage girls, identified and consulted relevant stakeholders (dieticians) who then provided valuable suggestions to their initial design concept. Another common weakness that was observed from the reviewed studies is the way mobile phones applications were evaluated for their effectiveness in inducing change of behaviour. The first issue is the length of period which is considerably short to observe permanent behaviour change. The reviewed studies showed that the longest observation period was 3 months minus the first week to establish a baseline. This is considerably shorter than Prochaska and Velicer [126] recommended minimum of 6 months. It was also found that different studies utilised different approaches to evaluate their application effectiveness, which in turn created difficulties in comparing the studies' results. A possible option to resolve this was to adopt a randomized controlled trial (RCT) which is commonly used in the health sciences. Fukuoka et al. [71] have published their detailed plan to evaluate the

effectiveness of their mobile phone application to increase physical activity in sedentary woman. However, it should be noted that, RCT may not provide an indication of why or how the mobile phone application could induce behavioural change. Therefore, if the aim of the evaluation is to find out the reasoning behind an induced behavioural change, additional qualitative data should be collected. There was also a question raised regarding the type of variables that were used to gauge the effectiveness of applications. For example, of two mobile phone applications that aimed to educate about healthy eating through game, one measured their application's effectiveness based on the frequency of use [73]; the other based it on the frequency of users' negative behaviour [95].

Emerging issues and future research directions

Following the increased acceptance of social network platforms and enthusiasm to share information publicly, it is expected that more and more mobile phone applications will enable sharing between peers. Sharing has been shown to have a positive relationship with inducing change of behaviour as a result of social pressure, support and accountability among members of a group [127, 128]. However, some of the studies that have incorporated this feature into their applications have reported issues that resulted from sharing such as unhealthy competitiveness [129], negative impacts if a desired response from peer was not received [30] and breach of privacy. More research will be required to avoid these issues whilst maximising the benefit of sharing between peers. Breach of privacy could also be an issue for mobile phone applications that integrate automatic sensing in various forms such as GPS, microphone, accelerometer. Klasnja et al. [130] reported that users' perception towards breach of privacy is influenced by the type of data that is recorded, the context in which participants worked and lived and the value they perceived would be gained in return. They suggested preventive measures such as adopting conservative recording and data retention policies, graded functionality for the sensors and giving users visibility and control over sensors usage. An issue that is unique to mobile phone applications with an advisory function is ensuring the appropriateness of suggestion with users' lifestyles and activities as well as the ability to ignore it. Fukuoka et al. [70], who sent daily random message to their application's users and required a subsequent response, found that only 39% and 34% of users would like to receive it once and twice a day, respectively. However, a study by Mutsuddi and Connelly [131] showed that tailoring suggestions is less crucial when an

application is deployed to users who are in the contemplation and preparation stages of change as they would likely more receptive to suggestion.

Throughout the review process of this paper, it was observed that there are limited guidelines on how to design effective mobile phone application interventions to sustain behavioural change. Although some research has begun to contribute to this topic, more research will be required in the future. Fogg [132], through his persuasive design concept, has proposed higher level abstraction that can be applied to persuade users while Consolvo et al. [100, 129] proposed several guidelines which were drawn from the implementation of their applications and incorporation of behavioural change theories. Their proposal included appropriate reward for positive reinforcement, supporting social influence, taking into account the practical constraints of users' lifestyles, reflection through abstraction, unobtrusive data collection and presentation, aesthetics, permitting the user to control their own data and enabling history/trend viewing. Another research direction for the future is a more comprehensive approach towards all dimensions of an individual's life. Lenert et al. [133] suggested that the lack of comprehensive approach might be an avenue to engage users in the long term after an initial period of interests. A comprehensive approach is only feasible when information regarding users is obtained and understood thoroughly. This is crucial for mobile phone applications that aim to be context-aware. More research which is also needed in the future is establishing the effectiveness of mobile phone applications, which has already been discussed in detailed in the previous section.

Summary

As discussed above, from User-Centred Design perspective, the design and development process of mobile phone applications can certainly be improved by addressing its current weaknesses. Two main areas offered opportunities for improvement. The first is design of an application should be based on a combination of thorough understanding of users and their contexts of use, combined with principles from behavioural change theories. The second is a more robust approach in evaluating the effectiveness of mobile phone applications in terms of chosen quantitative measures, length of observation periods and how and why certain features are successful in supporting behaviour change. More work is required to establish guidelines that can be used to design and develop mobile phone applications to prevent obesity.

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Appendix

Appendix A – A brief overview of mobile phones applications that were included in the review

		Underlying design concept	Targeted users	Role	Aim	Description of application
1.	**Activity Monitor [20, 21]**	Self awareness	*Not explicitly specified*	Tracking	Increasing physical activity	A context-aware mobile application that are based on recognition of movement and location capable to enable estimation and evaluation of the user's activity all day long.
2.	**ActiveShare [22, 23]**	Self awareness and social goal setting	Individual with sedentary life style	Enforcing social influence	Increasing physical activities	Users share goals by proposing physical activity challenges to others. Accepted physical activity challenge becomes new goal and recorded physical activities are shared among users
3.	**Arteaga et al. [24-26]**	Theory of Planned Behaviour, theory of Meaning Behaviour and Personality theory	Teenagers	Entertainment	Increasing physical activity	Users' personalities are identified and used to determine set of games relevant to their personalities. Motivational agent provides encouragement and positive reinforcement. User recorded manually the duration spent to play game.
4.	**BALANCE [27-29]**	*Not indicated*	*Not explicitly specified*	Tracking	Monitoring lifestyle	Users are provided with real-time feedback of their caloric intake/expenditure balance throughout the day by

						capturing their caloric intake through manual entries of food diaries and caloric expenditure through automatic detection of physical activity.
5.	**Chick Clique [20, 31]**	Goal setting, self-monitoring, positive reinforcement and social support	Teenage girls	Enforcing social influence	Increasing physical activity	Providing a group support system to promote walking towards a self-established daily step goals. Users entered step counts and shared them within the group with text message notification of step updates. Users can send motivating text messages to all or individual members of the group.
6.	**Android games [32, 33]**	*Not indicated*	Adolescents	Entertainment	Increasing physical activity	A suite of three different game applications to promote physical activities utilising accelerometer.
7.	**DiaTrace [34, 35]**	*Not indicated*	Children and adolescent obesity and overweight	Tracking	Autmatic recording of food and physical activity	Users' physical activities are recorded automatically through motion sensors. Users recorded their food intake by taking photos of each meat at the beginning which are later analysed manually by nutritionist.
8.	**Dietary Data Recording System [36-38]**	*Not indicated*	*Not explicitly specified*	Tracking	Automatic recording of food intake	Users are able to automatically calculate and log the caloric content of over nine thousand types of food, through the use a laser grid and a camera equipped mobile phone. Users are allowed to view an up-to-date summary of their daily eating habits.
9.	**DietCam [39]**	*Not indicated*	*Not explicitly specified*	Tracking	Automatic recording of food intake	Users take three images or a short video of the meal (prior and after the meal). Images/videos are then used to recognise, classify and estimate the volume and calorie

						content of the meal.
10.	**DiTS [40]**	*Not indicated*	Children with obesity	Entertainment	Increasing physical activity	A mobile phone version of the popular arcade game on dancing. Users worn 3-axis accelerometers that are worn around the players' ankles which record their legs movement with mobile phones to control the game and to display graphics
11.	**ExerTrek [41]**	*Not indicated*	*Not explicitly specified*	Tracking	Optimising physical activity's benefit	An exercise monitor on the mobile phone that will help an individual achieve a certain goal that users want from doing exercise. Once the goals and personal information are set for the individuals, it advises users to achieve the maximal benefits of their exercise without going beyond their own limits.
12.	**Fitness adventure [42, 43]**	*Not indicated*	*Not explicitly specified*	Entertainment	Increasing outdoor physical activity	An application platform to support physical outdoor exercise. It utilises location information and a mobile phone acts as a terminal device for the game.
13.	**Fitness Tour [44]**	*Not indicated*	School children and college students	Entertainment	To increase physical activity	Users are assigned an exercise tour, containing several locations, and shared their achievement through social media. Users' verification are required at each location. Users' heart beat were recorded at the start and end of the tour through a mobile phone's camera.

14.	**FoodLog [45, 46]**	*Not indicated*	*Not explicitly specified*	Tracking	Automatic recording of food intake	Users take photos of their food intake which are then analysed to estimate the nutritional composition of the meals. The food images and their calorie content are stored in a database and accessible to users who can also revise the calorie information.
15.	**Food Fight [47]**	*Not indicated*	Adult	Entertainment	Education in nutrition and healthy eating	Introducing competition between users through comparisons of their diets and the rating of their diet.
16.	**Health Defender [48, 49]**	Persuasive design	*Not explicitly specified*	Entertainment	Increasing physical activity	Users are required to make certain physical movement while wearing accelerometer as the primary game mechanic.
17.	**HealthAware [50]**	*Not indicated*	*Not explicitly specified*	Tracking	Monitoring lifestyle	Users monitor daily physical activity through embedded accelerometer and analyze food item by capturing food image with camera. Users are presented with activity counts at real time.
18.	**Houston [51, 52]**	Persuasive design	Individuals with obesity	Enforcing social influence	Increasing physical activity	Users are encouraged to perform physical activity by sharing step count with friends.
19.	**HyperFit [53]**	*Not indicated*	Individuals with overweight issue	Tracking	Mimic personal nutrition counselling	Users are provided with self evaluation tools for testing and goal definition, food and exercise diaries, analysis tools, and feedback and encouragement given by a virtual trainer.

20.	**iFitQuest [54,55]**	*Not indicated*	Adolescents	Entertainment	To increase physical activity	Users' real world physical movement is used to control their virtual character, interact with Non Player Character, visit landmarks and collect game items.
21.	**Impact [56]**	Self awareness	People with sedentary life style	Tracking	Monitoring physical activities	Users can capture number of steps, manually input the context of activities and review them on a web.
22.	**Into [57]**	*Not indicated*	*Not explicitly specified*	Tracking	To increase physical activity	The number of steps of a user, automatically recorded by in-built pedometer in a phone, is used to "proceed" (travel virtually) on a map. A use can play as an individual or a member of team.
23.	**KnowME [58]**	*Not indicated*	Overweight youth	Tracking	Monitoring physical activities	Users' biometric signals of users are monitored and visualising users' level of physical activity and sedentary behaviour.
24.	**LocoSnake [59]**	*Not indicated*	*Not explicitly specified*	Entertainment	To increase physical activity	A player embodies the snake and walks in the physical world to control it and get points.
25.	**Luften [60]**	*Not indicated*	Children with obesity or overweight issues	Entertainment	Increasing physical activity	Players are encouraged to move between the different zones through defined routes as their objectives of the game.
26.	**MashUps [61, 62]**	*Not indicated*	*Not explicitly specified*	Tracking	Monitoring lifestyle	Users are provided with a mobile service that collects data from a variety of health and wellbeing sensors and presented significant correlations across sensors in a mobile widget as well as on a mobile web application.

27.	**Mobile Snack [63]**	Social cognitive theory, health belief model, elaboration likelihood model, transportation theory and the precaution adoption process model.	Low socioeconomic status families	Tracking	Monitoring food intake	Users are provided with features to input and monitor snacking behaviour and receive feedback on snack healthiness.
28.	**Monster and Gold [64]**	*Not indicated*	People with sedentary life style	Entertainment	Trains and motivate users to jog outdoors	Users are provided with a context-aware and user-adaptive game which takes into account their heart rate, age, fitness level, and exercise phase.
29.	**MOPET [65, 66]**	*Not indicated*	*Not explicitly specified*	Advisory	Trains and motivate users to jog and perform exercise outdoors	User's positions during physical activity in an outdoor fitness trail are monitored to provide navigation assistance by using a fitness trail map and giving speech directions. An embodied virtual trainer shows how to correctly perform the exercises along the trail with 3D animations.
30.	**Motivate [67, 68]**	Persuasive design	*Not explicitly specified*	Advisory	Physical activity recommendation	Provides users with personalized and contextualized advice on possible physical activities to do
31.	**Move2PlayKids [69]**	Goal-setting, Self-awareness	Children aged 10 to 18	Tracking	To increase physical activity	Users' number of steps is obtained and their activities are inferred through GPS.

32.	**mPED [70, 71]**	*Not indicated*	Sedentary women	Tracking	Increasing physical activity	The mobile phone serves as a means of delivering the physical activity intervention, setting individualized weekly physical activity goals, and providing self-monitoring (activity diary), immediate feedback and social support. The mobile phone also functions as a tool for communication and real-time data capture.
33.	**NEAT-o-Games [72-74]**	*Not indicated*	*Not explicitly specified*	Entertainment	Increasing physical activity	Users physical activity are monitored and their level of activities control the animation of their avatars in a virtual race game with other players over the cellular network. Winners are declared every day and players with an excess of activity points are given rewards.
34.	**OrderUp [75, 76]**	Transtheoretical model	African American adults in the South-eastern US	Entertainment	Educate nutrition and healthy eating	Users learn how to make healthier meal choices by ordering healthy menu in the game.
35.	**[77, 78]**	*Not indicated*	*Not explicitly specified*	Tracking	Self monitoring system	Providing a self monitoring and expert guidance system on physical activities and calorie intakes.
36.	**PmEB [79, 80]**	Self-awareness	Overweight and obese adults	Tracking	Weight management	Users track their caloric balance by recording food intake and physical activity on their mobile phones. Daily reminder messages are also sent via SMS messages to encourage compliance.

37.	**Run, Tradie, Run [81]**	Persuasive design	*Not explicitly specified*	Entertainment	To increase physical activity	A player can purchase the in-game commodities using points that are earned by performing real physical activity
38.	**SapoFit [82, 83]**	*Not indicated*	*Not explicitly specified*	Enforcing social influence	Dietetic monitoring and assessment	Users keep daily Personal Health Record (PHR) of their food intake and daily exercise, and to share them with a social network.
39.	**Shakra [84, 85]**	Transtheoretical model and Social Cognitive Theory	Adult	Enforcing social influence	Increasing physical activity	Users physical activities are tracked through the fluctuation signal strength of their mobile phone and the results are shared with their peer.
40.	**SpyFeet [86, 87]**	*Not indicated*	Adolescent girls	Entertainment	To increase physical activity	Promoting physical fitness through addiction to an ongoing and compelling episodic interactive story whose progression is tied to exercise activities
41.	**Sportix [88, 89]**	*Not indicated*	*Not explicitly specified*	Entertainment	Increasing physical activity	Users are encouraged to perform physical activity by solving quests and performing sports.
42.	**StepUp [90]**	*Not indicated*	UAE population	Tracking	Increasing physical activity	It provides sensor-enabled mobile phones to automatically infer the number of steps the user walked and give the user a quantitative measure of his or her daily activities.
43.	**Technology Assisted Dietary Intake [91-93]**	*Not indicated*	*Not explicitly specified*	Tracking	Automatic recording of food intake	Users take mages of the meal which are then used to recognise, classify and estimate the volume and calorie content of the meal.
44.	**Time to eat [94, 95]**	Persuasive design	Children	Entertainment	To motivate healthy eating practice	Users learn about healthy eating by sending photos of the food they consumed to their virtual pet.

45.	**Triple Beat [96]**	Persuasive design	Runners	Entertainment	To optimise physical activity	assists runners in achieving predefined exercise goals via musical feedback and two persuasive techniques: a glanceable interface for increased personal awareness and a virtual competition
46.	**UbiFit [97-101]**	Goal-setting, Transtheoretical Model of Behaviour Change	*Not explicitly specified*	Tracking	To increase physical activity	Users can journal and review their physical activities and are shown abstract glanceable display of their physical activities each week on their phone's background screen.
47.	**Weight Management Mentor [102, 103]**	*Not indicated*	Individuals engaged in a weight lost program (meal replacement)	Tracking	Monitoring food intake and weight data	A user is proactively prompted and reminded to interact with the application & initiate health and self monitoring related tasks.
48.	**Walk2Build [104]**	Social participation	*Not explicitly specified*	Entertainment	To increase physical activity	Recorded GPS data and distance travelled are converted into steps and submitted to a server to create a city which can then be shared with other users.
49.	**Wellness Diary [105-108]**	CBT-based self-management	*Not explicitly specified*	Tracking	Monitoring lifestyle	Users can journal and review their lifestyle (weight, level of exercise, food intake etc)
50.	**WiFi Treasure Hunt [109]**	*Not indicated*	School children and college	Entertainment	To increase physical activity	A user is assigned with a random running tour consisting 10 locations with tree of the selected locations will have "hidden treasures".

			students			
51.	**Wockets [110]**	*Not indicated*	*Not explicitly specified*	Tracking	Monitoring physical activities	Capturing raw motion data to discriminate between activity types or to more accurately estimate energy expenditure
52.	**World of Workout [111]**	*Not indicated*	College students and gamers	Entertainment	To increase physical activity	A user levels up by working towards their goals and completing quests by achieving required number of steps.

Appendix B – A detailed review of mobile phone applications from UCD perspective

		Final outcome of studies	UCD Key Principles					
			Understanding of users, tasks and environment	**User involvement throughout design and development**	**Design was driven and refined by user-centred evaluation**	**Iterative design process**	**Addressing the whole user experience**	**Inclusion of multidisciplinary skills and perspective**
1.	**Activity Monitor [20, 21]**	Fully functioning prototype	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	Yes
2.	**ActiveShare [22, 23]**	Limited functioning prototype	User interviews with limited number of users (despite broad definition of users) for concept development.	Users were involved in design concept refinement and evaluation of prototype. Methods adopted were low fidelity prototyping, video prototyping, interviews and focus group.	Yes	Yes	Yes	Yes
3.	**Arteaga et al. [24-26]**	Fully functioning prototype	Survey and focus group were performed for targeted end-users.	Users were involved in concept development and evaluation of prototype.	*Not indicated*	*Not indicated*	Yes	Yes

4.	**BALANCE [27-29]**	Fully functioning prototype	*Not indicated*	Users were involved to validate automatic recognition of physical activities as well as design refinement for food diary (focus groups)	Yes	Yes	Not applicable	Yes
5.	**Chick Clique [20, 31]**	Fully functioning prototype	Informal interviews with dietitian; followed by exploratory field interviews and ethnography with targeted end-user.	Users were involved in design concept refinement and evaluation of prototype. Methods adopted were low and high fidelity prototyping, interviews and questionnaires.	Yes	Yes	Yes	Yes
6.	**Android games [32, 33]**	Fully functioning prototype	Scenarios were used to explore context of use but no users were involved.	Plan to involve user to evaluate high fidelity prototype	*Not indicated*	*Not indicated*	Not applicable	*Not indicated*
7.	**DiaTrace [34, 35]**	Fully functioning prototype	*Not indicated*	Users were *only* involved to validate automatic recognition of physical activities.	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*

8.	**Dietary Data Recording System [36-38]**	Fully functioning prototype	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
9.	**DietCam [39]**	Fully functioning prototype	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
10.	**DiTS [40]**	Fully functioning prototype	*Not indicated*	Users were involved in the evaluation of high fidelity prototype.	*Not indicated*	*Not indicated*	Yes	Yes
11.	**ExerTrek [41]**	Fully functioning prototype	*Not indicated*	Users were *only* involved in the evaluation of prototype.	*Not indicated*	*Not indicated*	*Not indicated*	*Yes*
12.	**Fitness adventure [42, 43]**	Fully functioning prototype	Extensive user studies were performed for concept development	Users were involved in design concept refinement and evaluation of prototype. Methods adopted were low and high fidelity prototyping, focus groups interviews and questionnaires.	Yes	Yes	Yes	Yes
13.	**Fitness Tour [44]**	Fully functioning prototype	*Not indicated*	Users are planned to be involved in the evaluation of the application	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*

14.	**FoodLog [45, 46]**	Fully functioning prototype	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
15.	**Food Fight [47]**	Fully functioning prototype	Interviews were conducted with targeted end-users and stakeholders.	Users were involved in design concept refinement and evaluation of prototype. Methods adopted were low and high fidelity prototyping and interviews.	Yes	Yes	Yes	Yes
16.	**Health Defender [48, 49]**	Fully functioning prototype	*Not indicated*	Users were involved in the evaluation of early prototype	Yes	Yes	Yes	Yes
17.	**HealthAware [50]**	Fully functioning prototype	*Not indicated*	Users were involved to validate automatic recognition of physical activities and a really limited user interface evaluation.	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
18.	**Houston [51, 52]**	Fully functioning prototype	*Not indicated*	Users were involved to validate functions of the prototype	*Not indicated*	*Not indicated*	Yes	Yes
19.	**HyperFit [53]**	Fully functioning prototype	Consumer survey and interviews with stakeholders	Users and stakeholders were involved in design concept refinement and evaluation of	Yes	Yes	Yes	Yes

				prototype.				
20.	**iFitQuest [54,55]**	Fully functioning prototype	End-users and expert interview were prformed	Users were involved in concept development and evaluation of prototype.	Yes	Yes	Yes	Yes
21.	**Impact [56]**	Fully functioning prototype	End-users studies were performed to establish system features	Users were involved in concept development and evaluation of prototype.	Yes	Yes	Yes	Yes
22.	**Into [57]**	Fully functioning prototype	End-users studies were performed to refine the concept and design aspects	Users were involved in concept development and evaluation of prototype.	Yes	Yes	Yes	Yes
23.	**KnowME [58]**	Fully functioning prototype	*Not indicated*	Users were *only* involved to validate energy expendire capturing.	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
24.	**LocoSnake [59]**	Fully functioning prototype	*Not indicated*	Users were involved in the evaluation of prototype.	*Not indicated*	*Not indicated*	Yes	*Not indicated*
25.	**Luften [60]**	Limited functioning prototype	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*

26.	**MashUps [61, 62]**	Fully functioning prototype	*Not indicated*	Users were involved in the evaluation of early prototype	*Yes*	Yes	Yes	*Yes*
27.	**Mobile Snack [63]**	Fully functioning prototype	*Not indicated*	Multiple cognitive walkthroughs were used for design concept refinement. Users were only involved in the evaluation of prototype through questionnaire.	Yes	Yes	Yes	Yes
28.	**Monster and Gold [64]**	Fully functioning prototype	*Not indicated*	Users were involved in the evaluation of high fidelity prototype.	Yes	Yes	Yes	Yes
29.	**MOPET [65, 66]**	Fully functioning prototype	*Not indicated*	Users were involved in the evaluation of high fidelity prototype.	Yes	Yes	*Not indicated*	Yes
30.	**Motivate [67, 68]**	Fully functioning prototype	*Not indicated*	Users were only involved in the evaluation of high fidelity prototype.	*Not indicated*	*Not indicated*	*Not indicated*	Yes
31.	**Move2PlayKids [69]**	Limited functioning prototype	*Not indicated*	Users were involved in the evaluation of a limited functioning prototype.	*Not indicated*	*Not indicated*	*Not indicated*	Yes
32.	**mPED [70, 71]**	Fully functioning	*Not indicated*	Users were only involved in the evaluation of high fidelity	*Not indicated*	*Not indicated*	*Yes*	Yes

		prototype		prototype.				
33.	**NEAT-o-Games [72-74]**	Fully functioning prototype	*Not indicated*	Users were only involved in the evaluation of high fidelity prototype.	*Not indicated*	*Not indicated*	Yes	*Yes*
34.	**OrderUp [75, 76]**	Fully functioning prototype	*Not indicated*	Users were only involved in the evaluation of high fidelity prototype.	*Not indicated*	Yes	Yes	Yes
35.	**[77, 78]**	Fully functioning prototype	*Not indicated*	Users were only involved in the evaluation of high fidelity prototype.	*Not indicated*	*Not indicated*	*Not indicated*	*Yes*
36.	**PmEB [79, 80]**	Fully functioning prototype	Scenarios were used to explore context of use but no users were involved.	Users were only involved in the evaluation of high fidelity prototype.	Yes	Yes	Yes	Yes
37.	**Run, Tradie, Run [81]**	Fully functioning prototype	End-users studies were performed to refine the concept and design aspects	Users were involved in concept development and will be included in the evaluation of prototype.	Yes	Yes	Yes	Yes
38.	**SapoFit [82, 83]**	Fully functioning prototype	*Not indicated*	Users were only involved in the evaluation of high fidelity prototype.	*Not indicated*	*Not indicated*	Yes	*Yes*

39.	**Shakra [84, 85]**	Fully functioning prototype	*Not indicated*	Users were only involved in the evaluation of high fidelity prototype.	*Not indicated*	*Not indicated*	*Yes*	Yes
40.	**Sportix [86, 87]**	Fully functioning prototype	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
41.	**Spy Feet [88, 89]**	Limited functioning prototype	Evaluation pilot on the concept of SpyFeet	Users were involved in the refinement of the SpyFeet concept.	Yes	Yes	Yes	Yes
42.	**StepUp [90]**	Fully functioning prototype	*Not indicated*	Users were only involved to validate accuracy of the sytem.	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
43.	**Technology Assisted Dietary Intake [91-93]**	Fully functioning prototype	*Not indicated*	Users were only involved in the evaluation of high fidelity prototype.	*Not indicated*	Yes	Yes	Yes
44.	**Time to eat [94, 95]**	Fully functioning prototype	Relevant stakeholders were consulted but no direct users involvement	Users were involved in the evaluation of prototype.	Yes	Yes	Yes	Yes
45.	**Triple Beat [96]**	Fully functioning	*Not indicated*	Users were involved in the evaluation of prototype.	*Not indicated*	*Not indicated*	*Yes*	*Yes*

		prototype						
46.	**UbiFit [97-101]**	Fully functioning prototype	Survey to potential users were performed.	Users were involved in concept development and evaluation of prototype.	Yes	Yes	Yes	Yes
47.	**Walk2Build [102]**	Limited functioning prototype	*Not indicated*	Users will be involved in the evaluation of a fully functioning prototype	*Not indicated*	*Not indicated*	*Not indicated*	Yes
48.	**Weight Management Mentor [103, 104]**	Fully functioning prototype	*Not indicated*	Users were involved in the evaluation of prototype.	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
49.	**Wellness Diary [105-108]**	Fully functioning prototype	*Not indicated*	Users were involved in concept development and evaluation of prototype.	Yes	Yes	Yes	Yes
50.	**WiFi Treasure Hunt [109]**	Fully functioning prototype	*Not indicated*	Users are planned to be involved in the evaluation of the application	*Not indicated*	*Not indicated*	*Not indicated*	*Not indicated*
51.	**Wockets [110]**	Fully functioning prototype	Partcipatory design with potential users were performed.	Users were involved in concept development.	Yes	Yes	Not applicable	Yes

52.	**World of Workout [111]**	Limited functioning prototype	*Not indicated*	Users were involved in the refinement of theWorld of Workout concept.	Yes	Yes	Yes	Yes