

Is it feasible to combine non-standard exercise prescriptions with novel smartphone adaptive coaching systems to improve physical activity and health related outcomes in type 2 diabetes mellitus?

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ABSTRACT

High levels of physical activity are paramount in ensuring individuals maintain or improve health outcomes, function and quality of life. However, physical activity continues to be low worldwide and rates of conditions associated with sedentary lifestyles are increasing. Furthermore, adherence to exercise prescriptions in individuals whose conditions are managed more effectively with physical activity is poor. This paper examines the feasibility of a novel adaptive coaching smartphone application in yielding a high adherence to an exercise programme, also specifically designed to improve physical activity habits of previously sedentary individuals with type 2 diabetes mellitus (T2DM) by encouraging adherence. The findings of the current study suggest that combining the specific novel exercise programme used in this study with a novel adaptive coaching smartphone application in sedentary individuals with T2DM is a feasible intervention. The findings also suggest that the combined intervention can yield high adherences, increase overall physical activity levels and improve health related outcomes.

Categories and Subject Descriptors J.3 [Computer Applications]: Life and Medical Sciences, Healthcare information systems, Health informatics, Human computer interaction

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Author Keywords

Adaptive coaching; Monitoring; Exercise; Type 2 diabetes mellitus.

1. INTRODUCTION

Physical activity is vital in preventing or delaying the incidence of, and in the treatment of, many chronic diseases, including T2DM [1, 2, 3]. Nonetheless, adherence to physical activity remains to be low in T2DM. Recommendations provided regarding levels of physical activity are consistently ignored and new methods of improving compliance to physical activity are required [4]. Recent evidence suggests that short bouts of independently conducted walking or step training spread throughout the day may yield high adherences and improve health outcomes in different populations, including individuals with T2DM. Similarly, progressive exercise programmes may encourage motivation over long periods but the combination of these elements has not been assessed.

Recent studies have also highlighted that smartphone coaching applications can improve health related outcomes in T2DM [5]. Automated coaching systems have also been shown to provide a cheap, private and convenient method of providing feedback to patients remotely. Furthermore, evidence suggests that computer based adaptive coaching systems can increase adherence to exercise programs [6]. These systems use theories of behavioural change to inform the automatic feedback provided to individuals to increase or maintain their motivation towards an exercise program and adjust the exercise prescription provided accordingly. The algorithms can regularly alter the level of physical activity prescribed to individuals based on their previous success to maintain motivation and adherence levels.

It seems plausible that a combination of novel approaches to exercise prescription and adaptive coaching strategies,

delivered within the framework of a smartphone application, could deliver a meaningful impact in the management of T2DM. However, to date, the feasibility of implementing the exact combination of these two elements, including the progressive short bout nature of the exercise programme, using a smartphone application has not been thoroughly evaluated across many populations, including in T2DM. This paper reports on ongoing study that aims to assess the feasibility of this combination being used over a 16-week period in previously sedentary individuals with T2DM. It will report on the adherence of the individuals to the programme and on the effects the intervention had on health-related outcome measures.

2. METHODS

2.1 Participants

7 individuals with T2DM for greater than 6 months (4 males, 3 females, 48.7 ± 5.5 years, BMI: 31.0 ± 2.8) were recruited through diabetes outpatients clinics in one public and one private hospital. They were undertaking less than 150 minutes per week of physical activity, not treated with insulin, and had a HbA1c of 53-86mmol/mol. Individuals with any mental, neurological, cardiovascular, musculoskeletal or orthopaedic deficiency contra-indicating training and/or muscular testing or making it impossible or preventing knowing consent to the study were not included. Individuals with current infectious or inflammatory condition, evidence of chronic renal failure or liver disease, severe proliferative diabetic retinopathy, current or recent pregnancy were also excluded. The University Human Research Ethics Committee approved the study protocol.

2.2 Study Protocol

The exercise programme was designed in a way to encourage high adherences and improve outcomes using recent evidence [7]. It consists of small bouts of walking and/or step training spread throughout the day. Participants choose either walking or step training for each individual session to provide them with greater autonomy and remove Irish weather as a barrier. Providing a choice of these exercise modalities is unique to this programme. Sessions gradually increased in length, frequency and intensity and participants were asked to incorporate the exercise programme into their routines over 16 weeks. The protocol started with 2-minute sessions twice/day at 12/20 on the Borg rating of perceived exertion (RPE) scale on 3 days for the first week and its duration, frequency and intensity progressed gradually to three 12-minute sessions every day at 16/20 on the Borg scale in week 16.

2.3 The adaptive coaching application

The “exercise and coaching application group” downloaded the adaptive coaching application onto their smartphone at baseline. This application automatically provided daily and weekly reminders and encouragement to complete prescribed exercise sessions, record recent sessions and

outlined the exercise session to be completed over the coming week. These messages included persuasive methods including positive and negative reinforcement including: “*Congratulations! You completed all of your last exercise prescription. Can you complete all of these sessions today?*” and “*Congratulations, you completed X% of exercise sessions in level Y. You are now progressing to level Z! Good luck!*” amongst others.

Participants also recorded their adherence in the application alongside a logbook. A function to record extra exercise sessions was also available (see figure 1). Upcoming exercise prescriptions were adapted by the application based on this information input by the individual participants. The application treated each week as a “level” and participants needed to complete 75% of sessions within an individual week to progress onto the next. If they failed to complete 75% of sessions, they remained on that level the following week. This smart, adaptive coaching used a combination of the “goal setting” and “self-efficacy” theories of behavioural change to find an exercise prescription that best encouraged participants to alter their behaviour and motivation towards the progressive exercise prescription by ensuring the programme was not too hard and not too easy [6]. It automatically alters the weekly exercise prescription given to individual participants based on their adherence the previous week and adjusts the daily and weekly feedback messages provided the individual in line with this.

Figure 1 A screenshot taken from the application showing the day's prescription, the recording function and the extra session function in the bottom right



2.4 Testing Protocol

Following recruitment, all participants attended laboratory facilities for testing before and after the 16-week intervention period. The testing protocol was outlined to participants when they arrived at the laboratory. They then completed a consent form, PAR-Q, Active Australia Survey and SF-36 questionnaire. Their height and weight were also recorded

and a six-minute walk test was conducted. Blood samples were taken and analysed in their diabetes clinics. Data is presented as means \pm standard deviation. All data was input into Microsoft Excel for analysis. Paired t-tests assuming equal variance were used to assess within group changes from baseline to follow up. A P value of ≤ 0.05 was considered statistically significant for all outcomes assessed.

3. RESULTS

Baseline characteristics of participants and dropout rates can be seen in table 1. Overall 2 of the 7 participants (28.6%) failed to complete the intervention. The reasons reported for dropping out were sudden onset of knee pain and an unknown reason. One individual was unable to complete the study as planned due to a series of personal family events that occurred at week 8 in the intervention period. This individual was included in the analysis.

Table 1 Baseline characteristics and dropouts

| (N = 7) | |
|--------------------------|-----------------|
| Female) | 3 |
| Dropouts | 2 (1 female) |
| Age (years) | 48.7 \pm 5.5 |
| BMI (kg/m ²) | 31.0 \pm 2.8 |
| Disease Duration (years) | 5.3 \pm 1.6 |
| HbA1C (mmol/mol) | 63.8 \pm 4.7 |
| Activity minutes/week | 72.9 \pm 45.6 |

Table 2 presents mean pre- and post-intervention data for those that completed the intervention period. P values presented are for within group differences from baseline. Some improvements in the health-related outcome measures were observed. Overall, adherences to prescribed exercise sessions was high. When the participant who did not complete the study as planned was removed from the analysis, mean adherence increased to 91.0 \pm 8.5%. Physical activity levels also increased from baseline in all participants although the mean increase for the 5 participants did not reach significance (see figure 2).

Table 2 Pre- and Post-Intervention data and adherence for individuals who completed the study.

| | Exercise and Coaching Application (N = 5, 2 female) | | |
|------------------------|--|-------------------|---------------|
| | PRE | POST | P |
| Activity minutes/ week | 92.0 \pm 46.6 | 291.4 \pm 231.7 | 0.13 |
| BMI | 30.2 \pm 2.6 | 29.0 \pm 2.3 | 0.53 |
| 6MWT (M) | 476.0 \pm 34.3 | 540.2 \pm 57.65 | 0.09 |
| HbA1C (mmol/mol) | 61.5 \pm 2.6 | 55.0 \pm 5.2 | 0.10 (n=4) |
| Sessions attempted (%) | 78.1 \pm 27.6 | - | - |
| Sessions completed (%) | 77.8 \pm 27.5 | - | - |

Pre- and post-intervention HbA1C data, a primary outcome for T2DM, was available for 4 participants. The relative

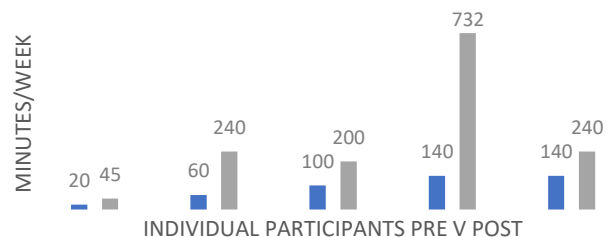
improvement was 10.6% for these participants. The relative improvements were 13.5% for 6MWT and 3.9% for BMI.

Table 3 presents the mean percentages of the different components of the SF-36 quality of life questionnaire. 6 of the 7 components of the questionnaire displayed a trend towards improving without statistical significance being reached. These improvements ranged from 12.5% to 33.3%. The mean of the General Health component did decrease marginally following the intervention period but this was also not statistically significant (-4.0%, P = 0.69).

4. DISCUSSION

The findings of the study indicate that by combining the novel simple exercise prescription with the novel smartphone adaptive coaching application used in the study, high adherences and increases in overall physical activity in previously sedentary type 2 diabetics can be produced. Furthermore, the intervention has the potential to improve health related outcomes in the population. Physical activity and minimising sedentary behaviour are fundamental tools used in the successful management of T2DM. The percent of sessions completed in the group, represent a high adherence for a 16-week exercise intervention of this magnitude (see figure 3). Nonetheless, despite the improvements in physical activity behaviour, 2 individuals in the group did not complete the study although for 1 individual this was due to injury. This highlights some of the challenges associated with yielding high adherences to physical activity in previously sedentary individuals.

Figure 2 Pre (blue) v post (grey) intervention self-reported physical activity for individual participants



The findings for improvements in HbA1C in the current study are promising and important clinically, as are the improvements in the other outcomes. T2DM is associated with low levels of physical activity and increases in glucose in the bloodstream [8, 9]. Reductions in HbA1C, indicate improvements in glycaemic control in the population. Although the improvements in the measure in the current study did not reach statistical significance, the sample sizes are small. Increasing the sample sizes may cause improvements to reach significance. This may also be the case for the other outcomes assessed. The general trend of the SF-36 scores is also encouraging as T2DM can have a major impact on the overall quality of life of individuals. These types of measures are important to consider when designing exercise interventions in this population and may provide a greater understanding of the overall impact of an intervention on individuals.

Table 3 Pre- and Post-Intervention SF-36 mean % scores

| | Exercise and Coaching Application (N = 5, 2 female) | | |
|--|--|-------------|------|
| | PRE | POST | P |
| Physical functioning | 78.0 ± 18.6 | 92.0 ± 7.5 | 0.20 |
| Role limitations due to physical health | 75.0 ± 38.7 | 95.0 ± 10.0 | 0.35 |
| Role limitations due to emotional problems | 40.0 ± 49.0 | 73.3 ± 38.9 | 0.32 |
| Energy/fatigue | 48.0 ± 21.6 | 68.0 ± 20.6 | 0.22 |
| Emotional wellbeing | 57.6 ± 27.3 | 71.2 ± 24.2 | 0.47 |
| Social functioning | 67.5 ± 28.1 | 80.0 ± 25.7 | 0.53 |
| Pain | 76.5 ± 27.7 | 95.5 ± 9.0 | 0.23 |
| General health | 59.0 ± 12.4 | 55.0 ± 15.2 | 0.69 |

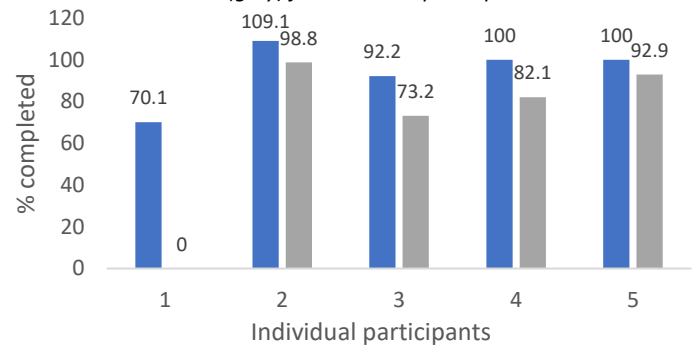
The smartphone adaptive coaching application used in the current study presents a novel tool to increase physical activity in previously sedentary populations. Although previous studies have assessed the efficacy of coaching applications in various populations, few, if any, have evaluated the use of a smartphone based adaptive coaching application designed explicitly for a novel 16-week exercise prescription that is aimed at yielding high adherences and improving outcomes. As the study period is only 16 weeks in duration, future work should examine the efficacy of the combination of the progressive exercise intervention and the adaptive coaching application over longer periods. It may be the case that the interventions are less effective over longer periods. Nonetheless, the findings of the current study indicate that the adaptive coaching application is effective in the short term and should be considered in clinical settings in previously sedentary individuals with T2DM. Likewise, similar adaptive coaching applications and exercise prescriptions should also be trialled in other sedentary populations. Smartphone applications present a major opportunity to clinicians for altering behaviours to improve health outcomes in a wide number of populations.

Future work should increase the sample size to allow for the effects of the interventions seen in the current sample to be confirmed. Furthermore, a larger sample size would allow a more accurate evaluation of the coaching application, regarding its effects on adherence and overall physical activity to be made. An evaluation of the efficacy of the intervention in comparison to just providing the exercise intervention to participants would also allow the effectiveness of the application independently to be made. Examining its use in other sedentary populations with chronic conditions or at risk of developing a chronic condition should also be conducted. If efficacious, this intervention or similar could be employed by health bodies to improve the quality of life of patients and reduce the burden on healthcare systems.

The current study indicates that the novel smartphone adaptive coaching application designed to be used with a simple novel exercise prescription, that was also designed for this study and involved non-standard exercise parameters is

a feasible and promising intervention. It may have the potential to yield high adherences, increase physical activity and improve health related outcomes and quality of life in sedentary individuals with T2DM over 16 weeks. Future work is needed to confirm the efficacy of this application and similar adaptive coaching applications with larger sample sizes, over longer periods with longer and/or different exercise programmes and in different populations. It may be that smartphone adaptive coaching applications in conjunction with specific exercise prescriptions that are also designed to boost adherence and improve health related outcomes bring about the greatest improvements in compliance, quality of life and health status.

Figure 3 % of exercise sessions completed in weeks 1-7 (blue) and weeks 8-16 (grey) for individual participants



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