Economic evaluation of the dr. Bart app in people with knee and/or hip osteoarthritis

Authors: Tim Pelle, Karen Bevers, Frank van den Hoogen, Job van der Palen, Cornelia van den Ende

Sponsor: Sint Maartenskliniek

Corresponding author:

Tim Pelle, PhD, PT

Department of Rheumatology, Sint Maartenskliniek, Nijmegen, the Netherlands.

Department of Rheumatic Diseases, Radboud University Medical Center, Nijmegen, the Netherlands

PO Box 9011, 6500 GM Nijmegen, the Netherlands.

Tel: +31 24 352 9148. Fax: +31 24 365 9204

Email: T.Pelle@maartenskliniek.nl / Tim.Pelle@radboudumc.nl

Karen Bevers, MD, PhD

Department of Rheumatology, Sint Maartenskliniek, Nijmegen, the Netherlands.

Email: K.Bevers@maartenskliniek.nl

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/ACR.24608

This article is protected by copyright. All rights reserved
**Objective** To evaluate the cost-utility and cost-effectiveness of the dr. Bart app compared to usual care in people with knee/hip OA, applying a health care payer perspective.

**Methods** This economic evaluation was conducted alongside a 6-month randomized controlled trial, involving 427 participants. The dr. Bart app is a stand-alone eHealth application which invites users to select pre-formulated goals (i.e. “tiny habits”) and triggers to a healthier lifestyle. Self-reported outcome measures were health care costs, quality-adjusted life years (QALYs) according to the EuroQol (EQ-5D-3L), and the EuroQol Visual Analogue Scale (QALY-VAS), patient activation measure (PAM-13) and five subscales of KOOS/HOOS. Missing data were multiply imputed and bootstrapping was used to estimate statistical uncertainty.

**Results** Mean age of participants was 62.1 (SD 7.3) years, with the majority being female (72%). Health care costs were lower for the intervention group (€-22 (95% CI: -36; -3)). For QALY and QALY-VAS, the probability of the dr. Bart app being cost-effective compared to usual care was 0.71 and 0.67 at a willingness to pay (WTP) of €10.000 and 0.64 and 0.56 at WTP €80.000, respectively. For self-management behaviour, symptoms, pain and ADL, the probability that dr. Bart app was cost-effective was >0.82 and for activities and quality of life <0.40, regardless of WTPs.

**Conclusion** This economic evaluation showed that costs were lower for the dr. Bart app group compared to usual care. Given the non-invasive character of the intervention and the moderate probability of being cost-effective for the majority of outcomes, the dr. Bart app has the potential to serve as a tool to provide education and goal setting regarding OA and its treatment options.

**Trial registration:** Dutch Trial Register (Trial Number NTR6693/NL6505) (https://www.trialregister.nl/trial/6505)

**Funding** This project is funded within the INTERREG-programme and receives financial support by the European Union, the Ministry of Economic Affairs, Innovation, Digitalisation and Energy of the State of North Rhine-Westphalia, the Ministry of Economic Affairs and Climate Policy of the Netherlands, and the Dutch Provinces of Gelderland and Limburg.

**Significance and innovation**

- This is the first study that performed an economic evaluation of a stand-alone (e-)self-management tool for people with knee/hip OA.

- This economic evaluation shows, from a health care payer perspective, that an (e-)self-management tool for knee/hip OA has moderate probabilities of being cost-effective.
Background

OA is a chronic disease mainly affecting the knee(s) and hip(s) resulting in pain, stiffness, and functional disability(1,2). Apart from this health burden, the financial annual burden of OA was 1.4% of the total health care expenditure in the Netherlands in 2017; € 1.2 billion. Costs attributable to OA among patients in secondary care (i.e. orthopaedic surgeon, rheumatologist, or physician assistant) are 8.6 times higher (629 vs. 73 million) than costs spent in primary care (e.g. general practitioner or physical therapist) (3). Due to the ageing population and increase in obesity, it is expected that the (economic) burden of OA will increase dramatically in the near future.(1,4).

First choice non-surgical treatments for knee/hip OA are education, lifestyle advice and healthy behaviours(5,6). Since OA is a chronic disease, a key element in non-surgical management is self-management(7,8). Compared to usual care, traditional self-management programs show small benefits on self-management skills, pain, function and symptoms(9). In the Netherlands, conservative treatment modalities (i.e. information, analgesics, physical therapy, and weight management) are coordinated in primary care, where the general practitioner functions as a gatekeeper for OA patients. When these conservative treatments have failed, patients are referred to secondary care(10). Despite recommendations about the content of non-surgical treatment options in OA, the quality of care is suboptimal in various European countries, including the Netherlands; lack of time results in underutilization of non-surgical treatment options and unnecessary referrals to secondary health care in people with knee/hip OA(11).

Due to the considerable costs related to OA, there is need for cost-effective interventions in the treatment for people with knee/hip OA. EHealth technologies(e.g. applications) offer the possibility to provide self-management 24/7 at lower costs compared to traditional interventions. EHealth interventions can be divided in blended interventions which combine face-to-face consultations with eHealth, and in eHealth applications without therapeutic guidance. By using interventions without therapeutic guidance, the burden of OA on health care will be less for providers, but for patients as well, as they do not need to travel and can apply it at their own pace(12). By providing education and self-management interventions without therapeutic guidance, eHealth interventions can provide high-reach, low-cost, accessible and scalable solutions for the scarce resources. Despite the high potential of these applications, the majority of applications have not proven their (cost-)effectiveness in trials in people with OA(13). Within mental healthcare and cardiac rehabilitation, blended interventions have been found to be cost-effective(14,15), while one study in people with knee/hip OA showed that a blended intervention was not cost-effective compared to usual physiotherapy (16). On the other hand, previous reviews
indicate that eHealth interventions have the potential to reduce treatment costs in musculoskeletal conditions (17,18). Yet, high quality evidence regarding economic evaluations in standalone applications without therapeutic guidance for people with knee/hip OA is lacking.

Given the huge potential of eHealth technologies, we developed the dr. Bart app to enhance self-management in people with knee/hip OA. The dr. Bart app is based on the Fogg model for behavioural change, augmented with reminders, rewards and self-monitoring to reinforce app engagement (19). We hypothesized that use of dr. Bart would result in better self-management (and thus reduction of secondary health care consumption) and improvement of pain and functioning. However, in our evaluation regarding the dr. Bart app we did not find changes in health care utilization over six months between the control and intervention group. On the other hand, the dr. Bart app has small but positive effects on pain, symptoms and activities of daily living in people with knee/hip OA (20). Given the scarce health resources, the growing economic burden as a consequence of rising prevalence of OA and the fact that prior studies did not assess joint uncertainty around cost and effects it is important to conduct an economic evaluation. Moreover, to be implemented on a larger scale, insight in the cost-effectiveness is warranted. Therefore, this study presents the (incremental) cost-utility analysis and cost-effectiveness analyses of the dr. Bart app compared to usual care in people with knee/hip OA over 6 months, from a health care payer perspective.

**Methods**

**Design overview**

We conducted this economic evaluation alongside a randomized controlled trial (RCT) evaluating the effectiveness of the dr. Bart app on health care use (HCU) and clinical outcomes over half a year, performed by the Sint Maartenskliniek Nijmegen (the Netherlands) from January 2018 to January 2019 (19,20). This economic evaluation was based on the general principles of cost-utility analysis and cost-effectiveness analysis, from a health care payer perspective, comparing a fully automated eHealth application with care as usual. Details of the trial design and development of the dr. Bart app have been published elsewhere (19). Ethical approval for this study was asked for and waived by the local Medical Research Ethics Committee of the Radboud University Medical Centre, Nijmegen (CMO Arnhem-Nijmegen; Protocol Number: 2017-3625/Dutch Trial Register NTR6693). This study is reported according the CHEERS statement (21).

**Participants**
Participants were recruited via newspapers and campaigns on social media (e.g. Facebook and LinkedIn). Potential participants were invited to visit the website (www.drbart.eu) to check for eligibility. Participants were included when: 1) Having self-reported OA of the knee and/or hip (i.e. having a painful knee and/or hip, knee and/or hip pain >15 days of the past month, morning stiffness <30 minutes (knee) and/or <60 minutes (hip)), 2) ≥50 years, 3) Having an e-mail address, 4) Possession of smartphone or tablet and willing to download the dr. Bart application on one or more devices and 5) Able to read, write and sufficiently communicate in Dutch.

Participants were excluded when: 1) being wheelchair bound, 2) diagnosis of (other) inflammatory rheumatic disease, 3) knee and/or hip replacements and 4) scheduled for knee and/or hip joint arthroplasty in next 6 months (19).

Participants who fulfilled baseline assessment were allocated to either intervention group (dr. Bart app) or control group (usual care) in a 1:1 ratio performed with CastorEDC by the researcher (TP). Further details regarding the study population can be found in our papers (19,20).

**Intervention; dr. Bart app**

We developed the dr. Bart app to enhance self-management and to actively involve people with OA in managing their disease. The dr. Bart app is a fully automated eHealth application and its main function is to set goals for a healthier lifestyle based on the Fogg model for behavioural change (22). The dr. Bart app is augmented with reminders, rewards and self-monitoring to reinforce app engagement and health behaviour. The dr. Bart app proposes goals to a healthier lifestyle on the basis of machine learning techniques fed by data collected in a personal profile and previous choosing behaviour of the user. Further details regarding the applied theoretical framework and development of the dr. Bart app are published elsewhere (19). Participants allocated to the intervention group received an e-mail with information to access the dr. Bart app.

**Control group; usual care**

Half of the participants were allocated to the usual care group and received no active treatment. Participants allocated to the control group received an e-mail that they were assigned to the control group. After fulfilling the last follow-up questionnaire, participants in the control group were offered the dr. Bart app as well.

**Outcome measures**
Participants were assessed at baseline, and after 3 and 6 months. Demographic data were collected at baseline.

**Utility measures**

We measured health-related quality with the EQ-5D-3L(23). The questionnaire differentiates between 245 health states(23). These health states were converted into utility units by using the Dutch tariffs(24). We calculated utility scores on a scale anchored at 0 (“The worst health you can imagine”) to 1 (“The best health you can imagine”). Moreover, the EuroQol Visual Analogue Scale (VAS) was used to indicate health-related quality of life on a vertical line ranging from 0 (“The worst health you can imagine”) to 100 (“The best health you can imagine”). We transformed the VAS-score into a utility score using the formula(25):

\[
\text{Transformed VAS} = (1 - \frac{1 - VAS}{100})^{1.61}
\]

We determined quality adjusted life years (QALYs) for each participant with the trapezoid method(26).

**Clinical outcome measures**

Knowledge, skills and confidence to cope with one’s health were assessed with the Patient Activation Measure(PAM-13) questionnaire(27,28). We used the KOOS or HOOS where applicable to assess pain, symptoms, activities of daily living, quality of life and physical functioning in sport and recreation(0-100), with higher scores indicating fewer complaints(29,30).

**Cost outcome measures**

Costs included health care costs related to knee/hip OA during the study. We opted for a health care perspective as we assumed that health care cost would be the main cost drivers in the current study. Self-assessed direct medical costs were assessed at baseline, and at 3 and 6 months of follow-up.

**Health care costs**

Participants received online cost questionnaires at baseline, after 3 and 6 months of follow-up. Health care costs included in the current study were costs related to knee/hip OA health care resource utilization over the period of half a year (assessed with a three-month recall period). Resources comprised the number of consultations with all relevant health care providers(Supplement 1). We assessed the number of consultations with a rheumatologist, orthopaedic surgeon, and physician assistant in secondary care. Moreover, we assessed the costs of outpatient care days, hospitalization and surgery in secondary care. For primary care we assessed the number of consultations with a general practitioner,
physical therapist, occupational therapist, exercise therapist, and dietician. Health care utilization was valued by Dutch standard cost prices of 2014(31), converted to 2018 price levels using the Dutch price index rate (i.e. 1.041).(31,32) To determine health care costs, we multiplied the number of visits with the accompanying price per resource. To estimate costs of knee/hip OA related surgery, we obtained prices of surgical operations from the Dutch Health Authority (www.nza.nl).

**Intervention costs**

We did not take development costs of the eHealth intervention into account in this economic evaluation.

**Statistical analysis**

All statistical analyses were performed using Stata 13.1 (www.stata.com). Statistical analyses were performed according to the intention-to-treat principle. Descriptive statistics were used to present group characteristics.

Missing data was managed according to the recommendations of the specific questionnaire. For the PAM, we also calculated a total score when a maximum of two items of the questionnaire were missing, though the PAM recommends to only calculate a total score if no single item is missing. For this, we calculated the mean score of the answered questions in the PAM questionnaire and multiplied this by 13.

Multiple imputation by changed equation was used to estimate missing cost and utility data. A total of 20 imputed datasets were predicted based on available data. The imputation model included variables related to the outcomes, and all available baseline and follow-up cost and effect measure values. For the cost-utility analysis we drew bootstrap samples from each of the multiply imputed datasets and estimated the difference in net benefit between the treatment groups in each bootstrap sample, given a WTP per QALY. The proportion of bootstrap samples in which the net benefit is positive represents the probability that the treatment is cost-effective for each multiply imputed dataset. This probability is then averaged across all multiply imputed datasets(33). Multiple imputed datasets were analyzed using Rubin rules (Stata command: ‘mi estimate’) (34).

We used longitudinal linear mixed models with random intercept, but without random slopes to evaluate the effectiveness of the dr. Bart app on clinical outcomes, adjusted for baseline values. Our primary analysis focused on the costs and effects over 6 months of follow-up. Differences in mean fitted predicted values were used to indicate group differences.
For the cost utility analysis and cost-effectiveness analysis, we reported incremental net monetary benefit (iNMB), because this measure is easier to interpret than the ICER when differences are small and around zero. The iNMB was calculated with the formula: iNMB = Willingness to Pay (WTP) * (incremental effect) – incremental costs (35). Uncertainty (95 % CI (confidence interval)) around costs and effects were estimated by percentile bootstrap intervals with 2500 replications. Bootstrapped incremental cost-effect pairs were plotted on cost-effectiveness planes (36). Moreover, we plotted cost-effectiveness acceptability curves to indicate the probability of the dr. Bart app being cost-effective compared to usual care at different willingness-to-pay values (€ 0 to € 80,000) (37). Results presented in Tables and Figures are based on society’s willingness to pay €10,000.

Sensitivity analyses

We performed two sensitivity analyses. First, we performed a per-protocol analysis excluding one participant from the control group (protocol violator), whereas in the intervention group 63 participants were considered non-adherent with the dr. Bart app (i.e. who did not choose at least one goal) and therefore excluded. For the second sensitivity analysis, we imputed missing data on health care utilization with a zero, when not being loss to follow-up. For the second sensitivity analyses, we imputed missing utility measures according to the last observation carried forward principle.

Results

Participants

In total, 427 participants were included in this economic evaluation; 214 allocated to the dr. Bart app group and 213 to the usual care group (Figure 1). Baseline characteristics were similar for both groups; mean age was 62.1 years (SD 7.3), with the majority being female (71.7%) and having symptoms predominantly in their knee(s) (73.3%). Almost 60% experienced symptoms due to OA less than five years (Table 1). The response rate for the follow-up questionnaires were 75.4% (intervention group, n=150; control group, n=172) and 69.3% (intervention group, n=130; control group, n=166) at 3 and 6 months, respectively.

Utilities

We found no differences in utility measures for the usual care group and the dr. Bart app group (mean group difference QALY 0.00 (95%CI: -0.00; 0.01) and QALY-VAS -0.00 (95%CI: -0.00; 0.00), Table 2.

Effects
After 6 months, no significant differences were seen in clinical outcomes between the dr. Bart app group and usual care group after bootstrapping (2500 replications), except for self-management behaviour (Table 3).

**Health care costs**

The estimated mean health care costs during follow-up were €503 (SE 79) and €462 (SE 80) for the control group and dr. Bart app group, respectively (Table 2). Over the period of six months the estimated difference between groups was lower for the dr. Bart app group (€-22 (95% CI: -36; -3)).

**Cost-utility analysis**

The primary economic evaluation of the current study was the cost-utility analysis comparing the difference between the dr. Bart app and control group in healthcare costs to the difference in QALY and QALY-VAS, obtained with the EQ-5D-3L. Since both costs and QALYs were in favour of the dr. Bart app group (i.e. dr. Bart app dominates control group) the iNMB was also in favour of the dr. Bart, regardless of society’s WTP (Table 3, Figure 2). We found an iNMB of €53 (95% CI: 11; 94) at a WTP of €10,000. Accordingly, the cost-effectiveness acceptability curve (CEAC) for QALYs showed a probability of the dr. Bart being cost-effective of 0.71 and 0.64, for a WTP of €10,000 and €80,000, respectively.

For QALY-VAS, we found an iNMB of €29 (-2; 60). At a WTP of €10,000, we found a probability of the dr. Bart app being cost-effective of 0.67. At higher WTPs, this probability decreased. The net benefit between groups did not reach statistical significance.

**Cost-effectiveness analysis**

Since both costs and self-management behaviour were in favour of the dr. Bart app group, the iNMBs were also in favour of the dr. Bart app, regardless of society’s WTP (Table 3, Supplement 3). The CEAC showed a probability of 0.99 of the dr. Bart app being cost-effective, regardless of society’s WTP.

For symptoms, pain and activities of daily living we found iNMBs of €20,000 to €30,000 at a WTP of €10,000, none statistically significant (Table 3, Supplement 4, 5, and 6). Accordingly, the CEAC showed that the probability of dr. Bart app being cost-effective compared to usual care was 0.93, 0.97, and 0.82 at different WTPs for symptoms, pain, and activities of daily living, respectively.

For activities and quality of life, assessed with either HOOS or KOOS, we found iNMBs of €7,000 in favour of the control group (Supplement 7 and 8). The CEAC showed that the probability of dr. Bart being cost-
effective was 0.37 and 0.36 for activities of daily life and quality of life. At higher WTPs, this probability remained about the same.

Sensitivity analyses

Our first sensitivity analysis (per-protocol analysis) gave similar results (Table 2 and Supplement 9 & 10) as our main analysis. In addition, we performed a second sensitivity analyses (in which we imputed missing cost data with a zero), and found comparable results (€ -31 (-66; 3) (Table 2 and Supplement 9 & 11) as our main analysis.

Discussion

We performed an economic evaluation of the dr. Bart app versus usual care in patients with knee/hip OA, from a health care payer perspective. We found small differences in health care costs in favour of the dr. Bart app group. Our analyses showed that both utility measures resulted in dominance for the dr. Bart app group, regardless of threshold for willingness to pay. Furthermore, 4 out of 6 clinical outcomes showed a chance of > 0.80 that the dr. Bart app was cost-effective at WTP thresholds between €10,000 and €80,000.

Regardless of the limited clinical outcomes(20), we considered it important to conduct an economic evaluation as these analyses are necessary to implement interventions on a larger scale. In addition, an important aim of self-management interventions is to actively involve people with OA to manage their disease, including skills navigating the health care system (i.e. making optimal use of primary and secondary health care options)(38). In the current economic evaluation we found no differences in utility measures between both study groups over six months, which is in line with two systematic reviews on traditional self-management interventions in OA(9,39), indicating that these interventions are not cost-effective, when measured with quality-adjusted life-years(39). On the other hand, we found that the dr. Bart has high chances of being cost-effective (> 0.80) in four out of six clinical outcomes. This might suggest that for non-pharmacological conservative treatments in OA, clinical outcomes are more responsive to change over time than utility measures. Taken together, there seem to be some inconsistencies over a range of utility measures and clinical outcomes. Overall, our findings seem to be indicative for moderate to high chances of dr. Bart app being cost-effective, albeit modest.

Although we a found moderate to high probability of the dr. Bart app being cost-effective for the majority of outcomes, differences in costs were small. The small differences in costs might be explained by the fact that our six month follow-up is too short to appropriately investigate whether the dr. Bart app
reduces secondary health care costs in the long-term. It is conceivable that the “tiny habits”(22) will be incorporated in daily life by participants, resulting in larger health benefits and changes in HCU patterns over time. In addition, one could hypothesize that differences in costs over time will rise because orthopedic surgery might be necessary or patients will become impaired and have loss of productivity, leading to higher net cost savings. This is underlined by two studies showing that non-pharmacologic conservative treatment programs can postpone and thus reduce the number of total joint replacements after 5 years(40,41). The relatively small net saving found in the present study could be of importance given the high prevalence of OA and its burden on society. Further research should be undertaken to investigate the long-term (cost-)effectiveness of non-pharmacologic conservative treatment (including self-management) interventions.

The growing prevalence of OA will result in an additional demand on health care services. Therefore, there is a need for cost-effective interventions in the non-pharmacological conservative treatment of OA. At present evidence about the cost-effectiveness of stand-alone eHealth applications to enhance self-management in people with OA is absent. As a consequence, no proper comparison of our economic evaluation with other studies is possible. Currently there is limited evidence for cost-effectiveness of a blended web-based option in OA(16), as well as for telemedicine in other chronic conditions (e.g. diabetes). Nevertheless, these studies remark that telemedicine has the potential to be cost-saving when appropriately executed(17,18). Therefore, more high quality or intensive self-management interventions accompanied with economic evaluations are necessary to enlarge our understanding on the cost-effectiveness of eHealth applications that enhance self-management in chronic conditions, especially in OA.

This is the first study that performed an economic evaluation of a stand-alone (e-)self-management application for people with knee/hip OA. A potential limitation of this study is the self-reported nature of HCU; self-reports are susceptible to underreporting and recall bias. However, we used the same cost questionnaire for the intervention and control group, i.e. underreporting would be similar in both groups. To minimize recall bias, we have chosen a recall period of three months. In our opinion, there is no better alternative to assess HCU as OA does not require continuous supervision of a physician, like in other chronic conditions (e.g. diabetes and COPD) and thus verifying data from other sources is not possible(42,43). A second potential limitation is the missing data on health care costs. We performed multiple imputations, which is considered highly appropriate to account for missing data. Third, this economic evaluation was conducted alongside a clinical trial and the required sample size was based upon the primary outcome of the RCT. Since costs have a larger variation and skewness than clinical outcome.
measures, the current study might be underpowered. (44,45) Fourth, one should bear in mind that we applied a health care payer perspective in this economic evaluation. Thus, productivity losses were not taken into account. We assumed that (secondary) health care costs would be the main driver in the current study. This is underlined in a cost-effectiveness study on a blended intervention in knee/hip OA; two-thirds of costs emerges from direct health care costs. Another potential limitation might be that we used the EQ-5D-3L rather than the EQ-5D-5L, while the 5L was developed to improve the 3L’s sensitivity. Last, it should be mentioned that we recruited participants for participation in a study on eHealth. This might have resulted in a selection of participants. Thus, generalizability is restricted to people with knee/hip OA who have an interest in using modern technologies to manage their disease. A strength of the performed study is that we performed not only a cost-utility analysis based on two different utility measures, but also used six different clinical outcomes to estimate cost-effectiveness, enabling trade-off between a range of benefits.

Considering the abovementioned results and limitations, this economic evaluation from a health care payer perspective, shows moderate probability that an eHealth application to enhance self-management (dr. Bart app) in people with knee/hip OA can be considered cost-effective. In view of the prevalence of OA and the fact that inducing difficult lifestyle changes is the cornerstone of management of OA and therefore a potentially long-term investment, we think the magnitude of effects attributable to the dr. Bart app are worthwhile. Thus, the app could be applied as primary approach to deliver useful information and support self-management in people with knee/hip OA, specifically for patients who are interested in eHealth.

**Declarations**

**Ethics approval and consent to participate**

Ethical approval for this study was asked for by the local Medical Research Ethics Committee of the Radboud University Medical Centre, Nijmegen (Protocol Number: 2017-3625). They concluded that the study fell outside the remit of the law for Medical Research Involving Human Subjects Act. This study is registered in the Dutch trial register (trial number: NTR 6693). All participants gave digital consent to participate in the present study.

**Availability of data and material**

The datasets used and/or analyzed in the present study are available from the corresponding author on reasonable request.
Competing interests

The authors declare that they have no competing interests

Funding

This project is funded within the INTERREG-programme and receives financial support by the European Union, the Ministry of Economic Affairs, Innovation, Digitalisation and Energy of the State of North Rhine-Westphalia, the Ministry of Economic Affairs and Climate Policy of the Netherlands and the Dutch Provinces of Gelderland and Limburg. The funding body had and will not have any role in the design of the study and collection, analysis, and interpretation of the data and writing and submitting manuscripts.

Authors’ contributions

TP, KB, JvdP, FHJvdH and CHMvdE participated in the design of the study. TP was responsible for inclusion and data collection. TP, JvdP, and CHMvdE were responsible for data analysis, tables and figures. All authors were responsible for interpretation of data. TP and CHME were responsible for drafting the manuscript, all other authors critical reviewed the manuscript. Furthermore, all authors approved the final version of the manuscript.

Acknowledgements

A special thanks to all participants for their contribution to this study.

We would like to thank Laura Rodwell for her statistical support.

We would like to thank Symax B.V. and Orikami B.V. who helped to develop the dr. Bart app.

References

1. Cross M, Smith E, Hoy D, Nolte S, Ackerman I, Fransen M, et al. The global burden of hip and knee osteoarthritis: estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis [Internet]. 2014 Jul;73(7):1323–30. Available from: http://ard.bmj.com/lookup/doi/10.1136/annrheumdis-2013-204763

2. Allen KD, Golightly YM. State of the evidence. Curr Opin Rheumatol [Internet]. 2015
3. Volksgezondheidenzorg.info. Artrose [Internet]. RIVM Bilthoven. 2019 [cited 2019 Feb 22]. p. RIVM Bilthoven. Available from: https://www.volksgezondheidenzorg.info/onderwerp/artrose

4. Deshpande BR, Katz JN, Solomon DH, Yelin EH, Hunter DJ, Messier SP, et al. Number of Persons With Symptomatic Knee Osteoarthritis in the US: Impact of Race and Ethnicity, Age, Sex, and Obesity. Arthritis Care Res (Hoboken) [Internet]. 2016 Dec;68(12):1743–50. Available from: http://doi.wiley.com/10.1002/acr.22897

5. Bannuru RR, Osani MC, Vaysbrot EE, Arden NK, Bennell K, Bierma-Zeinstra SMA, et al. OARSI guidelines for the non-surgical management of knee, hip, and polyarticular osteoarthritis. Osteoarthr Cartil [Internet]. 2019 Nov;27(11):1578–89. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1063458419311161

6. Fernandes L, Hagen KB, Bijlsma JWJ, Andreassen O, Christensen P, Conaghan PG, et al. EULAR recommendations for the non-pharmacological core management of hip and knee osteoarthritis. Ann Rheum Dis [Internet]. 2013 Jul;72(7):1125–35. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23595142

7. Barlow J, Wright C, Sheasby J, Turner A, Hainsworth J. Self-management approaches for people with chronic conditions: a review. Patient Educ Couns [Internet]. 2002;48(2):177–87. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12401421

8. Lorig KR, Holman H. Self-management education: history, definition, outcomes, and mechanisms. Ann Behav Med [Internet]. 2003 Aug;26(1):1–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12867348

9. Kroon FP, van der Burg LR, Buchbinder R, Osborne RH, Johnston R V, Pitt V. Self-management education programmes for osteoarthritis. In: Buchbinder R, editor. Cochrane Database of Systematic Reviews [Internet]. Chichester, UK: John Wiley & Sons, Ltd; 2014. p. 10–3. Available from: http://doi.wiley.com/10.1002/14651858.CD008963.pub2

10. Kroneman M, Boerma W, van den Berg M, Groenewegen P, de Jong J, van Ginneken E. The Netherlands: health system review. Heal Syst Transition, 2016. 2016;18(2):1–239.

11. Østerås N, Jordan KP, Clausen B, Cordeiro C, Dziedzic K, Edwards J, et al. Self-reported quality care for knee osteoarthritis: comparisons across Denmark, Norway, Portugal and the UK. RMD open
12. Bossen D, Veenhof C, Van Beek KE, Spreeuwenberg PM, Dekker J, De Bakker DH. Effectiveness of a Web-Based Physical Activity Intervention in Patients With Knee and/or Hip Osteoarthritis: Randomized Controlled Trial. J Med Internet Res [Internet]. 2013 Nov 22;15(11):e257. Available from: http://www.jmir.org/2013/11/e257/

13. Marcolino MS, Oliveira JAQ, D’Agostino M, Ribeiro AL, Alkmim MBM, Novillo-Ortiz D. The Impact of mHealth Interventions: Systematic Review of Systematic Reviews. JMIR mHealth uHealth [Internet]. 2018 Jan 17;6(1):e23. Available from: http://mhealth.jmir.org/2018/1/e23/

14. Donker T, Blankers M, Hedman E, Ljótsson B, Petrie K, Christensen H. Economic evaluations of Internet interventions for mental health: a systematic review. Psychol Med [Internet]. 2015 Dec 3;45(16):3357–76. Available from: https://www.cambridge.org/core/product/identifier/S0033291715001427/type/journal_article

15. Kraal JJ, Van den Akker-Van Marle ME, Abu-Hanna A, Stut W, Peek N, Kemps HM. Clinical and cost-effectiveness of home-based cardiac rehabilitation compared to conventional, centre-based cardiac rehabilitation: Results of the FIT@Home study. Eur J Prev Cardiol [Internet]. 2017 Aug 23;24(12):1260–73. Available from: http://journals.sagepub.com/doi/10.1177/2047487317710803

16. Kloek CJJ, van Dongen JM, de Bakker DH, Bossen D, Dekker J, Veenhof C. Cost-effectiveness of a blended physiotherapy intervention compared to usual physiotherapy in patients with hip and/or knee osteoarthritis: a cluster randomized controlled trial. BMC Public Health [Internet]. 2018 Aug 31;18(1):1082. Available from: http://www.ncbi.nlm.nih.gov/pubmed/30170586

17. Lee JY, Lee SWH. Telemedicine Cost–Effectiveness for Diabetes Management: A Systematic Review. Diabetes Technol Ther [Internet]. 2018 Jul;20(7):492–500. Available from: http://www.liebertpub.com/doi/10.1089/dia.2018.0098

18. Teljeur C, Moran PS, Walshe S, Smith SM, Cianci F, Murphy L, et al. Economic evaluation of chronic disease self-management for people with diabetes: a systematic review. Diabet Med [Internet]. 2017 Aug;34(8):1040–9. Available from: http://doi.wiley.com/10.1111/dme.13281

19. Pelle T, Bevers K, van der Palen J, van den Hoogen FHJ, van den Ende CHM. Development and evaluation of a tailored e-self-management intervention (dr. Bart app) for knee and/or hip osteoarthritis: study protocol. BMC Musculoskelet Disord [Internet]. 2019 Dec 31;20(1):398.
Available from: https://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/s12891-019-2768-9

20. Pelle T, Bevers K, van der Palen J, van den Hoogen FHJ, van den Ende CHM. Effect of the dr. Bart application on healthcare use and clinical outcomes in people with osteoarthritis of the knee and/or hip in the Netherlands; a randomized controlled trial. Osteoarthr Cartil [Internet]. 2020 Apr;28(4):418–27. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1063458420309006

21. Husereau D, Drummond M, Petrou S, Carswell C, Moher D, Greenberg D, et al. Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement. Eur J Health Econ [Internet]. 2013 Jun;14(3):367–72. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23526140

22. Fogg BJ. A behavior model for persuasive design. In: Proceedings of the 4th International Conference on Persuasive Technology - Persuasive ’09 [Internet]. New York, New York, USA: ACM Press; 2009. p. 1. Available from: www.bjfogg.com

23. EuroQol Group. EuroQol--a new facility for the measurement of health-related quality of life. Health Policy [Internet]. 1990 Dec;16(3):199–208. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10109801

24. Lamers LM, Stalmeier PFM, McDonnell J, Krabbe PFM, van Busschbach JJ. Measuring the quality of life in economic evaluations: the Dutch EQ-5D tariff. Ned Tijdschr Geneeskd [Internet]. 2005 Jul 9;149(28):1574–8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16038162

25. Stiggelbout AM, Eijkemans MJC, Kiebert GM, Kievit J, Leer J-WH, De Haes HJCJM. The 'Utility' of the Visual Analog Scale in Medical Decision Making and Technology Assessment: Is It an Alternative to the Time Trade-off? Int J Technol Assess Health Care [Internet]. 1996 Mar 10;12(2):291–8. Available from: https://www.cambridge.org/core/product/identifier/S0266462300009648/type/journal_article

26. Drummond MF, O’Brien B, Stoddart GL, Torrance GW. Methods for the economic evaluation of health care programmes. 2nd ed. New York: Oxford University Press; 1997.

27. Skolasky RL, Green AF, Scharfstein D, Boult C, Reider L, Wegener ST. Psychometric properties of the patient activation measure among multimorbid older adults. Health Serv Res [Internet]. 2011 Apr;46(2):457–78. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21091470

This article is protected by copyright. All rights reserved
28. Rademakers J, Nijman J, van der Hoek L, Heijmans M, Rijken M. Measuring patient activation in The Netherlands: translation and validation of the American short form Patient Activation Measure (PAM13). BMC Public Health [Internet]. 2012 Jul 31;12:577. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22849664

29. de Groot IB, Favejee MM, Reijman M, Verhaar JA, Terwee CB. The Dutch version of the knee injury and osteoarthritis outcome score: A validation study. Health Qual Life Outcomes [Internet]. 2008 Feb 26;6(1):16. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18302729

30. de Groot IB, Reijman M, Terwee CB, Bierma-Zeinstra SMA, Favejee M, Roos EM, et al. Validation of the Dutch version of the Hip disability and Osteoarthritis Outcome Score. Osteoarthr Cartil [Internet]. 2007 Jan;15(1):104–9. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1063458406002020

31. Hakkaart-van Roijen L, Van der Linden N, Bouwmans C, Kanters T, Tan SS. Costing manual: Methodology of costing research and reference prices for economic evaluations in healthcare [in Dutch: Kostenhandleiding: Methodologie van kostenonderzoek en referentieprijzen voor economische evalua- ties in de gezondheidszorg]. 2015;

32. CBS StatLine - Bevolking; kerncijfers 2010.

33. Faria R, Gomes M, Epstein D, White IR. A Guide to Handling Missing Data in Cost-Effectiveness Analysis Conducted Within Randomised Controlled Trials. Pharmacoeconomics [Internet]. 2014 Dec 29;32(12):1157–70. Available from: http://link.springer.com/10.1007/s40273-014-0193-3

34. Rubin DB. Multiple Imputation for Nonresponse in Surveys [Internet]. Rubin DB, editor. Hoboken, NJ, USA: John Wiley & Sons, Inc.; 1987. (Wiley Series in Probability and Statistics). Available from: http://doi.wiley.com/10.1002/9780470316696

35. O’Brien BJ, Briggs AH. Analysis of uncertainty in health care cost-effectiveness studies: an introduction to statistical issues and methods. Stat Methods Med Res [Internet]. 2002 Dec;11(6):455–68. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12516984

36. Black WC. The CE plane: a graphic representation of cost-effectiveness. Med Decis Making [Internet]. 10(3):212–4. Available from: http://www.ncbi.nlm.nih.gov/pubmed/2115096

37. Fenwick E, O’Brien BJ, Briggs A. Cost-effectiveness acceptability curves--facts, fallacies and frequently asked questions. Health Econ [Internet]. 2004 May;13(5):405–15. Available from:
38. Smink AJ, van den Ende CHM, Vliet Vlieland TPM, Swierstra BA, Kortland JH, Bijlsma JWJ, et al. “Beating osteoARTthritis”: Development of a stepped care strategy to optimize utilization and timing of non-surgical treatment modalities for patients with hip or knee osteoarthritis. Clin Rheumatol [Internet]. 2011 Dec 2;30(12):1623–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21887488

39. Pinto D, Robertson MC, Hansen P, Abbott JH. Cost-Effectiveness of Nonpharmacologic, Nonsurgical Interventions for Hip and/or Knee Osteoarthritis: Systematic Review. Value Heal [Internet]. 2012 Jan;15(1):1–12. Available from: https://linkinghub.elsevier.com/retrieve/pii/S109830151103498X

40. Pisters MF, Veenhof C, Schellevis FG, De Bakker DH, Dekker J. Long-term effectiveness of exercise therapy in patients with osteoarthritis of the hip or knee: a randomized controlled trial comparing two different physical therapy interventions. Osteoarthr Cartil [Internet]. 2010 Aug;18(8):1019–26. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1063458410001615

41. Svege I, Nordsletten L, Fernandes L, Risberg MA. Exercise therapy may postpone total hip replacement surgery in patients with hip osteoarthritis: a long-term follow-up of a randomised trial. Ann Rheum Dis [Internet]. 2015 Jan;74(1):164–9. Available from: http://ard.bmj.com/lookup/doi/10.1136/annrheumdis-2013-203628

42. Hurley MV, Walsh NE, Mitchell HL, Pimm TJ, Williamson E, Jones RH, et al. Economic evaluation of a rehabilitation program integrating exercise, self-management, and active coping strategies for chronic knee pain. Arthritis Rheum [Internet]. 2007 Oct 15;57(7):1220–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17907207

43. Beckett M, Weinstein M, Goldman N, Yu-Hsuan L. Do health interview surveys yield reliable data on chronic illness among older respondents? Am J Epidemiol [Internet]. 2000 Feb 1;151(3):315–23. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10670557

44. Korthals-de Bos I, van Tulder M, van Dieten H, Bouter L. Economic Evaluations and Randomized Trials in Spinal Disorders: Principles and Methods. Spine (Phila Pa 1976) [Internet]. 2004 Feb;29(4):442–8. Available from: http://journals.lww.com/00007632-2004020150-00017

45. Tan SS, Teirlinck CH, Dekker J, Goossens LMA, Bohnen AM, Verhaar JAN, et al. Cost-utility of exercise therapy in patients with hip osteoarthritis in primary care. Osteoarthr Cartil [Internet]. 2016 Apr;24(4):581–8. Available from:
**Figure 1.** Flow chart of the study.

**Figure 2.** Cost-effectiveness plane for QALY.
Table 1. Baseline characteristics of participants allocated to the intervention (Dr. Bart pp) and control group (n=427).

|                                | Dr. Bart app group (n=214) | Control group (n=213) |
|--------------------------------|-----------------------------|-----------------------|
| Age, years; mean (SD)          | 62.1 (7.7)                  | 62.1 (7.0)            |
| Female, n(%)                   | 147 (68.7)                  | 159 (74.7)            |
| Body Mass Index, kg/m²; mean (SD) | 27.8 (5.1)                 | 27.3 (4.8)            |
| Level of education (≤ 12 years, n%) | 56 (28.0)                  | 36 (18.6)             |
| Main OA-location               |                             |                       |
| Knee, n(%)                     | 157 (73.4)                  | 156 (73.2)            |
| Duration of symptoms, n(%)     |                             |                       |
| - < 5 years                    | 129 (60.3)                  | 117 (54.9)            |
| - ≥ 5 – 10 years               | 85 (39.7)                   | 96 (45.1)             |
| Self-management behaviour      | 40.8 (5.3)                  | 40.2 (5.7)            |
| Symptoms†                      | 57.7 (16.3)                 | 57.0 (18.9)           |
| Pain†                          | 57.5 (15.5)                 | 58.2 (17.8)           |
| Activities of daily living†    | 58.5 (19.7)                 | 59.4 (20.2)           |
| Activities†                    | 32.6 (23.9)                 | 32.5 (23.1)           |
| Quality of life†               | 38.0 (17.5)                 | 38.3 (17.1)           |

Abbreviations; SD standard deviation, n Number, OA osteoarthritis †Assessed with either KOOS or HOOS.

†Assessed with either KOOS or HOOS
Table 2. Utility scores and average health care costs per patient during follow-up for the intervention and control group separately.

|                                | Dr. Bart app group<sup>†</sup> (N=214) | Control group<sup>†</sup> (N=213) | Group difference<sup>‡</sup> |
|--------------------------------|----------------------------------------|----------------------------------|------------------------------|
| QALY / Utility score (0.0 - 0.5), mean (SE) | 0.36 (0.07)                           | 0.36 (0.07)                      | 0.00 (-0.00; 0.01)           |
| QALY / Utility score VAS (0.0 - 0.5), mean (SE) | 0.42 (0.05)                           | 0.42 (0.04)                      | 0.00 (-0.00; 0.00)           |
| Total health care costs during follow-up, € mean (SE)<sup>a</sup> | 462 (80)                              | 503 (79)                         | -22 (-36; -3)                |
| Total health care costs during follow-up, € mean (SE)<sup>b</sup> | 489 (104)                             | 505 (80)                         | -8 (-25; 15)                 |
| Total health care costs during follow-up, € mean (SD)<sup>c</sup> | 439 (1294)                            | 496 (1240)                       | -31 (-66; 3)                 |

<sup>†</sup>Raw estimates *Mixed models, adjusted for baseline value, with 95% confidence interval obtained from bootstrapping with 2500 replications.

<sup>a</sup> Missing data were multiply imputed <sup>b</sup>Per-protocol analysis <sup>c</sup>When not loss to follow-up, missing data were imputed with zero cost.
Table 3 Differences in predicted mean costs and effects between the dr. Bart app group and control group.

| Outcome     | ΔC∞  | ΔE∞  | iNMB ∞ (€10,000) | iNMB ∞ (€80,000) | Distribution CE plane % |
|-------------|------|------|------------------|------------------|-------------------------|
|             | In euros | In points |                  |                  | **SE** | **NE** | **SW** | **NW** |
| QALY (0-1)  | -22  | 0.00 | 53 (11; 94)      | 274 (-25; 573)   | 62.5  | 0.3   | 36.2  | 1.0   |
| QALY-VAS (0-1) | -22  | 0.00 | 29 (-2; 60)      | 79 (-131; 292)   | 54.1  | 0.6   | 44.6  | 0.7   |
| PAM         | -22  | 1.2  | 12468 (3115; 22195) | 99593 (24826; 177381) | 98.0  | 1.4   | 0.6   | 0.0   |
| Symptoms    | -22  | 2.6  | 25856 (-8001; 58342) | 206695 (-64204; 466589) | 92.1  | 1.1   | 6.6   | 0.2   |
| Pain        | -22  | 3.0  | 30422 (-2008; 60726) | 243225 (-16217; 485562) | 95.6  | 1.3   | 3.0   | 0.1   |
| ADL         | -22  | -0.7 | 19017 (-22782; 61215) | 151984 (-182503; 489496) | 80.8  | 0.8   | 17.8  | 0.5   |
| Activities  | -22  | -0.7 | -7343 (-50573; 37943) | -58899 (-404788; 303379) | 36.4  | 0.2   | 62.2  | 1.2   |
| QoL         | -22  | -0.7 | -7194 (-47927; 31992) | -57706 (-383505; 255851) | 35.4  | 0.3   | 63.2  | 1.0   |
Positive sign indicates that the intervention is cost-effective compared to usual care at a given willingness-to-pay threshold (€10,000 or €80,000), after 2500 bootstrap replications.

Control group as reference.

Costs are expressed in 2018 Euros. Abbreviations: CE-plane: Cost-Effectiveness plane, INMB: increment Net Monetary Benefit

- **SE**: Southeast quadrant: indicating that Dr. Bart is more effective and less costly than usual care.
- **NE**: Northeast quadrant: indicating that Dr. Bart is more effective and more costly than usual care.
- **SW**: Southwest quadrant: indicating that Dr. Bart is less effective and less costly than usual care.
- **NW**: Northwest quadrant: indicating that Dr. Bart is less effective and more costly than usual care.
