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ORIGINAL RESEARCH ARTICLE

Cost–Benefit Analysis of the Enhancing Men's Awareness of Testicular diseases (E-MAT) Feasibility Trial: A Virtual Reality Experience to Increase Testicular Knowledge and Self-Examination among Male Athletes

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Abstract

Background Virtual reality (VR) is potentially effective in raising awareness of testicular diseases, promoting self-examination and early help-seeking among men. This paper presents an early economic evaluation exploring the potential cost-effectiveness of Enhancing Men's Awareness of Testicular diseases $(E\text{-}MAT)_{VR}$, a VR interactive experience compared with $E\text{-}MAT_E$, electronic information, among male athletes Results from this economic evaluation will inform and support the design of a future randomized controlled trial (RCT).

Methods Results from an Irish feasibility trial (ClinicalTrials.gov identifier: NCT05146466) with 74 participants conducted in 2022 were employed. Benefits were measured in monetary units whereby the contingent valuation method was used to elicit participants' preferences through willingness-to-pay measures. A micro-cost analysis estimated the costs of the intervention and comparator and subsequent resource use. The costs and benefits of $E\text{-}MAT_{VR}$ and $E\text{-}MAT_E$ were compared to determine the net benefit. Sensitivity analyses were also conducted.

Results Base case analysis suggests participants were willing to pay €21.88 for $E\text{-}MAT_{VR}$ and €11.16 for $E\text{-}MAT_E$. The total cost of $E\text{-}MAT_{VR}$ was €104.09 and of $E\text{-}MAT_E$ was €22.75 per participant. These estimates include capital and delivery costs, of which delivery costs were €25.02 and €22.40 for $E\text{-}MAT_{VR}$ and $E\text{-}MAT_E$, respectively. A negative net benefit indicates $E\text{-}MAT_{VR}$ was not cost-beneficial as delivered in the feasibility trial. Scenario analyses demonstrated reducing costs via delivery modifications increased the probability of $E\text{-}MAT_{VR}$ being considered cost-effective. The cost–benefit analysis was feasible, response rates were acceptable, and willingness-to-pay estimates were stable.

Conclusions Economic evaluations alongside feasibility trials enable early economic evaluations, informing the design and conduct of a future RCT. $E\text{-}MAT_{VR}$ had higher expected benefits (WTP) and costs than $E\text{-}MAT_E$, yielding a negative net benefit. Given the high cost of digital health interventions, investigating their cost-effectiveness early is important to inform and optimize resource allocation decisions. We present a series of scenarios to demonstrate how delivery modifications to reduce costs could improve the likelihood of $E\text{-}MAT_{VR}$ being considered cost-effective.

1 Introduction

Incidences of testicular cancer (TC), one of the most common malignancies in men under 50 years, have doubled internationally over the last 30–40 years, primarily affecting Caucasian men in Europe [1]. The most frequently reported sign of TC is a painless mass and 80% of such masses are benign [2]. Therefore, it is important that men are educated to practice testicular self-examination to familiarize themselves with what is normal for them and what is not [3].

Virtual reality (VR) may help raise testicular awareness and promote testicular self-examination and early help-seeking among men in general and young men in particular, who are often hard to reach in well-being initiatives [4]. This could help detect testicular diseases early, reduce treatment costs, and improve overall health outcomes [5]. Motivated by this, the aim of the Enhancing Men's Awareness

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Key Points for Decision Makers

While participants had higher willingness-to-pay for E-MAT$_{VR}$ than E-MAT$_{E}$, the net benefit was negative, indicating E-MAT$_{VR}$ was not cost-beneficial as delivered in the feasibility trial.

Scenario analyses demonstrated that reducing costs via delivery modifications increased the probability of E-MAT$_{VR}$ being considered cost-effective.

Feasibility trials facilitate early economic evaluations, informing the design and conduct of a future randomized controlled trial.

of Testicular diseases (E-MAT) feasibility trial was to pilot the effect of E-MAT$_{VR}$ (intervention: interactive experience using VR) compared with E-MAT$_{E}$ (control: electronic information delivered using a tablet) among male athletes and coaches engaged in Indigenous Gaelic games [6].

E-MAT$_{VR}$ is a three-level immersive education game delivered using a VR headset with voiceover and two controllers, designed to enhance men's awareness of testicular diseases, to measure help-seeking intentions for testicular symptoms and intention and behavior to feel their testes. It is an interactive gaming experience set in a virtual apartment with three distinct areas representing three game levels. E-MAT$_{VR}$ takes approximately 10 min to complete. Intervention development, feasibility, and acceptability are reported elsewhere [4–7]. Participants in the control group (E-MAT$_{E}$) received the same information as E-MAT$_{VR}$ delivered as plain text in portable document format (PDF), with screenshots from E-MAT$_{VR}$. E-MAT$_{E}$ participants were given up to 10 min to read the text and look at images using a tablet. Underpinned by the Preconscious Awareness to Action theoretical framework, we hypothesized in the trial that the mode of intervention delivery could impact on outcomes given that the interaction with the VR headset, and information delivered through the headset, could lead to long-lasting memory of the intervention and longer knowledge retention [8] in comparison with more conventional methods of information delivery (i.e., E-MAT$_{E}$).

A two-arm parallel-group randomized (1:1) pilot feasibility study was conducted [6]. Eligible participants were male, aged 18-50 years, resided in Ireland, and involved in Gaelic Athletic Association (GAA) as players or coaches. GAA is Ireland's largest amateur sports and cultural organization, focused on promoting Indigenous Gaelic games such as hurling, camogie, Gaelic football, Gaelic handball, and rounders [9]. Athletes engaged in such games as well as other field games are at an increased risk of testicular trauma and subsequent benign testicular diseases such as testicular torsion (i.e., twisting of the testis), given the contact nature of the sport [10, 11], hence the focus on male athletes from GAA clubs. Of note, symptoms of benign diseases can mimic those of TC, hence the focus of E-MAT on promoting men's awareness of the normal look and feel of their own testes, regardless of the ultimate diagnosis.

Individuals with a history of seizures or motion sickness were excluded. There is no gold standard for determining sample size in pilot feasibility studies, with recommendations ranging from as few as 10 to as many as 59 participants. For instance, Viechtbauer et al. [12] offered a formula for calculating sample size in pilot studies, noting that a problem occurring with a 5% probability in a participant will almost certainly be detected (with 95% confidence) in a study with 59 participants. Consequently, we set our sample size at 59. To account for an estimated attrition rate of 25%, we successfully recruited 74 participants into the feasibility trial. Recruitment involved social media and posters with QR codes over 6 weeks [13].

The feasibility trial took place in nine geographically distributed GAA sports clubs in County Cork in the Southwest of Ireland, over a 3-month period. For each of the nine participating GAA clubs, individual participants were randomized to either the intervention (E-MAT$_{VR}$) or control (E-MAT$_{E}$) arms using the Castor EDC software. After participants provided consent and their baseline assessments were entered into the software, they received their allocations via automated email. This process necessitated in-person administration of both E-MAT$_{VR}$ and E-MAT$_{E}$. Additionally, the intervention and control were administered in person, as certain aspects of the process evaluation required researchers to observe participants as they interacted with E-MAT$_{VR}$ and E-MAT$_{E}$. The full protocol for the feasibility trial is available online (ClinicalTrials.gov identifier: NCT05146466) [14], the process evaluation protocol and findings are published [6, 7], and recruitment details are in the study within a trial [13]. Our current study conducts an early cost–benefit analysis of the E-MAT feasibility trial, comparing E-MAT$_{VR}$ with E-MAT$_{E}$ for men to determine the potential net benefit and cost-effectiveness of the intervention to support a proposal for a full randomized controlled trial (RCT) and inform its design.

Digital health interventions are increasingly used, particularly to capture hard-to-reach audiences for specific treatment or disease management. Despite the growth in their use, a recent review concluded that evidence regarding the cost-effectiveness of digital health interventions is scarce [15] and only a few employ willingness-to-pay (WTP) methodologies. While several vehicles exist for eliciting values, i.e., open-ended, payment scale, closed-ended, or bidding/bargaining approaches, each with their own weaknesses

[16], many previous studies included open-ended WTP questions [17]. For example, an Irish study examined women's valuation of an integrated mobile phone application and stand-alone application for postoperative monitoring post-caesarean section, using an open-ended WTP question [18]. WTP levels were found to be considerably smaller than anticipated, possibly owing to participants' experiences with paying small amounts for mobile phone applications [19]. A Bangladeshi study examined WTP for mobile text messaging to promote diabetes self-management and found participants were generally willing to pay for the service and male participants with higher household income and higher levels of education reported higher WTP levels [19]. Somers et al. [17] examined WTP for a mobile health solution/application (mHealth) promoting well-being, using an open-ended question and confirmed participants' absolute WTP for access to the app and their marginal WTP. The study found consumers value mHealth solutions that promote well-being, social connectivity, and healthcare control, but it is not universally embraced. Our study contributes to this expanding literature examining cost-effectiveness of digital interventions, presenting an early economic evaluation to exploring the potential cost-effectiveness of E-MAT$_{VR}$, a VR interactive experience compared with E-MAT$_{E}$.

2 Methods

2.1 Estimating Willingness-to-Pay

We compared the costs and benefits of E-MAT$_{VR}$ with E-MAT$_{E}$ using the results from the E-MAT feasibility trial (Enhancing Men's Awareness of Testicular Diseases [E-MAT]: A Feasibility Study [ClinicalTrials.gov identifier: NCT05146466]) over a 3-month time period in 2022 [6, 14].

Benefits were measured in monetary units whereby the contingent valuation method (CVM) was used to elicit participants' preferences for the proposed intervention and comparator through WTP measures [20], guided by Frew et al. [21]. CVM can elicit values using open-ended, payment scale, closed-ended, or bidding/bargaining approaches, each with their own weaknesses [16]. Here, using a stated preference approach, participants were presented with hypothetical scenarios to infer how much they would be willing to pay to experience a welfare gain associated with the service. In line with previous studies [17–19], we adopt the open-ended WTP format for our question (Fig. 1) wherein each subject was invited to indicate their own WTP valuation, unbounded and unprompted [16], thus inferring how much they would be willing to pay for E-MAT$_{VR}$ and E-MAT$_{E}$. Open-ended questions offer greater flexibility, avoiding a starting point bias and offering a higher degree of individual variability than alternatives such as bidding game, payment care, or multiple-choice questions [19, 22].

The payment vehicle was designed as an out-of-pocket expense given participants' expected familiarity with out-of-pocket expenses for computer games, and is in line with previous studies considering other digital health interventions [17–19]. The CVM questions were distributed to the 74 men who participated in the 2022 feasibility trial. The study received ethical approval from the Clinical Research Ethics Committee in University College Cork (ECM 06/2023 PUB). The WTP responses employed in the analyses were collected pre-intervention (T0).

Once data were collected, cleaned, and entered into the statistical software package (Stata 18 [23]), analyses were employed to explore WTP. Descriptive statistics (with mean and median) were performed on the CVM to explore mean WTP among participants who provided a positive WTP value and the respondents who either failed to complete the WTP question (protest response) or who provided a zero WTP value. Given the inherent problems associated with zero and protest responses, initial comparisons across demographics are investigated using logistic regression [21]. Examining how these groups differ in terms of demographics is important to understand respondents' preferences.

All positive WTP values are explored in the first instance. Potential outliers are subsequently trimmed in a sensitivity analysis. Trimming the outliers is useful for removing potentially dubious responses [24]. Using regression analysis, WTP values are explored, choice of which depends on elicitation format [25]. As we have open-ended WTP questions and a censored sample, wherein the dependent variable cannot take a value less than zero (i.e., left-censored), we employed Tobit regression analyses [26].

2.2 Estimating Costs

To estimate the costs associated with E-MAT$_{VR}$ and E-MAT$_{E}$, a micro cost analysis was conducted. All unit costs were valued in 2022 prices and expressed in euros (€), and a healthcare provider perspective was assumed wherein only direct costs associated with intervention development and delivery were included. (Trial related costs were not included in the analysis.) Intervention development costs are traditionally considered a sunk cost, however, they have an associated opportunity cost. Thus, these are included in the base case analysis here as capital costs and are depreciated on a straight-line basis (10% per annum as per HIQA guidelines) [27]. Costs are categorized into personnel and materials. Personnel costs accounted for remuneration of staff time involved in E-MAT's development and delivery, including time spent traveling to GAA clubs to deliver the

Fig. 1 Contingent valuation method scenarios presented to respondents

Here we describe two options for enhancing men's awareness of testicular diseases and encourage them to examine their testicles and seek medical help for symptoms when appropriate. Please read the below two options carefully and complete the questions below:

Virtual Reality: A once off virtual reality (VR) game that uses light humour to educate men about testicular diseases and encourage them to examine their testicles and seek medical help for symptoms. It isdelivered using a VR headset, handheld controllers, and voiceover (all wireless). The game has three levels and takes approximately 10 minutes to complete. The user is required to complete one level to move to the next level. A voice over provides an introduction and instructs users on how to play the game to move to the next level. Key messages are reiterated, and users are instructed to recognise when they need to seek help and how to seek help for symptoms of testicular disease.

Electronic information: Users are provided with key messages on diseases that affect the testicle. They are also instructed on how to recognise when they need to seek help and how to seek help for testicular symptoms. This is done through a series of text and images saved on a plain text (PDF) file readable on a tablet such as an iPad. The file is approximately 3 pages long and all images are in colour. It takes approximately 5 minutes to read this information.

1) As a young man how much would be willing to pay out of your own pocket for the **virtual reality** game described above?

_€_____

2) As a young male how much would be willing to pay out of your own pocket for the **electronic information** described above?

__€_____

intervention and comparator. Personnel costs were estimated (as presented in Supplementary Table A1) using national salary scales per staff grade level as per national guidelines [27]. Materials refer to equipment used by staff to develop and deliver E-MAT$_{VR}$ and its comparator E-MAT$_{E}$. Quantities of each resource were identified and measured using project documentation, based on participant numbers, and were valued using market prices (details provided in Supplementary Table A2). The perspective of the study was then broadened in a scenario analysis to capture related healthcare utilization from baseline to follow-up (T2) (since they were exposed to E-MAT$_{VR}$ or E-MAT$_{E}$). A dedicated resource use questionnaire was designed and disseminated to participants capturing visits to general practitioners (GPs), emergency departments, outpatient clinics, and urgent care clinics (both public and private services). These were then valued from a patient and healthcare provider perspective to reflect the public–private mix in the Irish healthcare system.

2.3 Cost–Benefit Analysis

The cost and benefits of E-MAT$_{VR}$ and E-MAT$_{E}$ are compared by applying a cost–benefit analysis framework to determine the net benefit, where an intervention was considered cost-beneficial if the net benefit was positive: (Net Benefit = Benefits − Costs) [13]. Probabilistic sensitivity analyses were performed using Microsoft Excel to investigate the existence and extent of uncertainty in the WTP parameters (10,000 simulations, gamma distributions applied to willingness-to-pay parameters and costs were held constant, see Supplementary Material B for details and CHEERS checklist). Scenario analyses consider the impact of excluding intervention development costs and delivery modification on the intervention's cost-effectiveness. A breakeven analysis illustrates the scale needed to avoid a negative net benefit.

3 Results

3.1 Participants' Willingness-to-Pay

Sample size was 74, with various responses. Most respondents provided positive WTP values for both the intervention and comparator (74%). A minority provided zero values for both the intervention and comparator (8%) or just the intervention (3%) or comparator (15%). All respondents were male, aged between 21 and 38 years (average 28.6 years).

Most participants were university educated (85%, $n = 63$) and in employment (66%, $n = 49$). Very few had a history of testicular disease (2.7%, $n = 2$) and 32% ($n = 25$) indicated perceived risk of testicular disease as baseline (Table 1).

There was a statistically significant difference ($p = 0.0001$) between mean WTP for the two interventions when including and excluding zeros. The base case analysis suggests, on average, that participants are willing to pay €21.88 (95% CI 14.54, 29.21) for E-MAT$_{VR}$ and €11.16 (95% CI 7.6, 15.06) for E-MAT$_{E}$ (Table 2). When only the positive values are considered, this average increases to €26.95 (95% CI 17.48, 36.41) for E-MAT$_{VR}$ and €14.65 (95% CI 9.73, 19.58) for E-MAT$_{E.}$ Results indicate positive skewness and kurtosis for E-MAT$_{VR}$ and E-MAT$_{E}$, when zeros and outliers are included and excluded. The WTP data also enable identification of the participants' preference structure for the two interventions. Clear preferences are observed (i.e., greater WTP), with 48 participants (65%) preferring E-MAT$_{VR}$.

Logistic regression results (Table 3) demonstrate no statistically significant relationships between participant characteristics and give a zero response for either E-MAT$_{VR}$ or E-MAT$_{E}$. The Tobit regression results (Table 4) indicate no statistically significant relationships between participant characteristics and WTP for E-MAT$_{VR}$. However, there is a statistically significant, negative relationship between WTP for E-MAT$_{E}$ and being a GAA player and being Irish, respectively.

Table 1 Descriptive statistics of sample

Variable	Full sample ($n = 74$)	Positive values only ($n = 55$)
	Mean/% (Std. dev.)	Mean/% (Std. dev.)
Age	28.57 (8.48)	29.36 (9.24)
Player	80% (0.40)	76% (0.43)
Irish	99% (0.12)	98% (0.13)
Single	54% (0.50)	53% (0.50)
Education: third level	85% (0.36)	84% (0.37)
History of testicular disease	3% (0.16)	2% (0.13)
Perceived risk[a]	32% (0.47)	31% (0.47)
Student	27% (0.45)	27% (0.45)
Employed	66% (0.48)	67% (0.47)
Self-employed	1% (0.12)	2% (0.13)
Unemployed	– –	– –
Student and employed	5% (0.23)	4% (0.19)

[a]Participants' perceived risk of testicular diseases was assessed using one item, wherein the level of agreement was measured on a 5-point Likert scale. See [5].

3.2 Cost Estimates

The total cost of the E-MAT$_{VR}$ intervention per participant was €104.09 and the comparator E-MAT$_{E}$ was €22.75 (Table 5). The capital costs accounted for 72% of E-MAT$_{VR}$ total costs and 2% for E-MAT$_{E}$ total costs. With regard to intervention delivery costs (see Supplementary Table A2 for details), most of the costs were attributable to travel expenses by personnel to participants' GAA clubs and their time delivering E-MAT$_{VR}$ and E-MAT$_{E.}$

From the dedicated survey, only four participants recorded related healthcare utilization at 3-month follow-up (T2), three of whom received E-MAT$_{VR}$ and one E-MAT$_{E}$. These participants had one ($n = 3$) or two ($n = 1$) visits to the GP for testicular pain ($n = 3$) or testicular injury ($n = 1$). This was followed by attendance at an emergency department for treatment ($n = 1$), outpatient clinic for follow-up ($n = 1$), and urgent care clinics for diagnostic tests (such as ultrasound or other) (public [$n = 1$] and private [$n = 1$]). The participant who reported attending the GP following a testicular injury had received E-MAT$_{E}$ and was referred to the emergency department for further treatment. The corresponding total costs for resource use for E-MAT$_{VR}$ and E-MAT$_{E}$ were €922.04 and €159.51, respectively, or €24.92 and €4.31 on average per participant (see Supplementary Table A2).

3.3 Cost–Benefit Analysis and Scenario Analyses

The cost–benefit analysis suggests that E-MAT$_{VR}$ cannot be considered cost-beneficial as delivered in the feasibility trial (Table 6). A negative net benefit (€82.21) is produced, as costs exceed participants' WTP in the base case and also when patient costs (healthcare resource use costs) are considered in scenario analysis 1 (€107.13). Digital products have high associated capital costs with their development, as is evident here with E-MAT$_{VR}$. However, often such fixed costs are considered a sunk cost and are excluded from economic evaluations. When this scenario is adopted here (i.e., only delivery costs are considered), the net benefit for E-MAT$_{VR}$ remains negative for mean WTP estimates (scenario analysis 2).

Table 2 Descriptive statistics willingness to pay for the E-MAT virtual reality and comparator interventions across samples

	Variable	Obs	Mean	Std. dev.	Min	Max	Median	Skewness	Kurtosis
Observed	WTP E-MAT$_{VR}$ (full sample)	74	21.878	31.66	0	200	10	3.63	18.41
	WTP E-MAT$_{E}$ (full sample)	74	11.162	16.85	0	100	5	2.88	12.92
	WTP E-MAT$_{VR}$ (positive response only)	55	26.945	35.02	5	200	20	3.25	14.65
	WTP E-MAT$_{E}$ (positive response only)	55	14.655	18.22	1	100	10	2.57	10.57
	WTP E-MAT$_{VR}$ (full sample, 95% inliers)	71	16.465	15.50	0	80	10	1.59	6.03
	WTP E-MAT$_{E}$ (full sample, 95% inliers)	71	9.662	13.37	0	50	5	2.11	6.59
	WTP E-MAT$_{VR}$ (positive response only, 95% inliers)	52	21.673	19.40	0	100	16	1.99	7.56
	WTP E-MAT$_{E}$ (positive response only, 95% inliers)	52	13.173	14.22	2	50	10	1.77	4.90
Adjusted[a]	WTP E-MAT$_{VR}$ (full sample)	74	21.8784	8.8847	5.85	50.00	19.55	0.81	3.60
	WTP E-MAT$_{E}$ (full sample)	74	11.1622	7.1840	1.85	50.00	9.08	2.52	12.93
	WTP E-MAT$_{VR}$ (positive response only)	55	26.9455	12.9889	2.56	63.48	27.16	0.47	3.20
	WTP E-MAT$_{E}$ (positive response only)	55	14.6546	8.2886	0.99	50.00	12.88	1.71	7.70
	WTP E-MAT$_{VR}$ (full sample, 95% inliers)	71	16.4648	5.5827	7.91	50.00	15.45	2.95	19.46
	WTP E-MAT$_{E}$ (full sample, 95% inliers)	71	9.6620	5.5773	3.44	50.00	9.23	5.40	39.84
	WTP E-MAT$_{VR}$ (positive response only, 95% inliers)	52	19.8462	7.2334	6.57	50.00	20.09	1.22	7.32
	WTP E-MAT$_{E}$ (positive response only, 95% inliers)	52	12.8077	6.4556	3.36	50.00	11.67	3.70	22.45

[a]Adjusted using the predicted values of the Tobit regressions. See Table 4

One aim when conducting economic evaluations of feasibility trials such as this one is to inform the conduct of future RCTs. In the feasibility trial, travel costs were high—a contributing factor was multiple recruitment visits to some GAA clubs. Some clubs had a local champion who coordinated the participants facilitating a single visit, thereby reducing travel costs. Scenario analysis 3 demonstrates how a single coordinated visit (nine clubs and average four participants per club) would reduce delivery costs by 30% and 38% for E-MAT$_{VR}$ and E-MAT$_{E}$, respectively, generating positive net benefits for E-MAT$_{VR}$ (when capital costs are excluded). Finally, as the E-MAT feasibility trial's aim was to prepare for a RCT, the sample size was small at 74 and not powered enough to detect an effect. It is likely future deployment would have greater sample sizes that would reduce costs per person, impacting net benefit. A breakeven analysis demonstrates when costs and WTP estimates are assumed to remain constant; increasing sample size in the E-MAT$_{VR}$ arm to 43 (from 37) would yield a positive net benefit if only delivery costs are considered, or to 177 when including capital costs as well. Results of the probabilistic sensitivity analysis, across 10,000 simulations, were used to estimate the probability of a positive expected net benefit for E-MAT$_{VR}$ and E-MAT$_{E}$ and the probability that E-MAT$_{VR}$'s expected net benefit is greater than the expected net benefit of E-MAT$_{E}$ (Fig. 2). Results demonstrate variability between the base case and scenario analyses, suggesting perspective and scope matter, and delivery modifications could increase the likelihood that E-MAT$_{VR}$ is considered cost-effective compared with E-MAT$_{E}$.

Table 3 Logit regressions: protest/blank willingness to pay estimates

	(1) Zero response E-MAT$_{VR}$ & E-MAT$_{E}$	(2) Zero response E-MAT$_{VR}$,	(3) Zero response E-MAT$_{E}$
	Coefficient	Coefficient	Coefficient
	Std error	Std error	Std error
Age	0.946	0.367**	1.084
	− 0.06	− 0.164	− 0.084
Player	1.131	0.003*	3.303
	− 1.171	− 0.009	− 4.37
Single	1.013	0.032	1.404
	− 0.637	− 0.083	− 1.037
Third level education	1.971	0.347	5.237
	− 1.962	− 0.831	− 7.381
History testicular disease	3.222	Omitted	3.285
	− 4.755		− 4.867
Student	0.229	0.001*	1.452
	− 0.278	− 0.003	− 2.303
Employed	0.383	3.539	0.497
	− 0.47	− 7.597	− 0.769
Reported zero WTP for E-MAT$_{E}$	n/a	919.105**	n/a
		− 2728.772	
Reported zero WTP for E-MAT$_{VR}$	n/a	n/a	27.181***
			− 28.835
Intercept	2.222	1.29E+12	0.002
	− 5.665	− 1.78E+13	− 0.006
Number of observations	72	70	72

Explanatory variables: Age in years, binary variables: role in GAA, 1 = player, 0 other (e.g., coach); nationality, 1 = Irish, 0 otherwise; marital status, 1 = single, 0 otherwise; education, 1 = third level, 0 less than third level; history of testicular disease 1 = yes, 0 otherwise; perceived risk of testicular disease 1 = yes, 0 otherwise; occupational status (student, employed, self-employed, unemployed, student_employed) dummy variables:1= yes, 0 otherwise. Model (I) Zero Response E-MAT$_{VR}$ & E-MAT$_{E}$: Irish = 1, predicts failure perfectly; Irish omitted and 1 obs not used. Self_employed = 0 predicts failure perfectly; self_employed omitted and 1 obs not used. Unemployed omitted because of collinearity. Student_employed omitted because of collinearity. Model (2) Zero Response E-MAT$_{VR}$. Irish = 1 predicts failure perfectly; irish omitted and 1 obs not used. History = 0 predicts failure perfectly; history omitted and 2 obs not used. Self_employed = 0 predicts failure perfectly; self_employed omitted and 1 obs not used. Unemployed omitted because of collinearity. Student_employed omitted because of collinearity. Model (3) Zero Response E-MAT$_{E}$. Irish = 1 predicts failure perfectly; Irish omitted and 1 obs not used. Self_employed = 0 predicts failure perfectly; self_employed omitted and 1 obs not used. Unemployed omitted because of collinearity. Student_employed omitted because of collinearity

***$p < 0.01$, **$p < 0.05$, *$p < 0.10$

4 Discussion and Limitations

This early economic evaluation assesses the potential cost-effectiveness of E-MAT$_{VR}$ compared with E-MAT$_{E}$ among male athletes on the basis of experiences in the feasibility trial [6]. Results support and inform the design and conduct of a future RCT. Compared with E-MAT$_{E}$, E-MAT$_{VR}$ had higher expected benefits and costs, but expected costs outweigh WTP estimates, yielding negative net benefit. The higher costs were attributable to the capital costs associated with developing and delivering the intervention. Scenario analyses demonstrated whether intervention delivery costs were reduced via alternative delivery strategies in the RCT, and if WTP estimates remained constant, E-MAT$_{VR}$ could be considered cost-effective. Furthermore, distributing costs across more participants (as would be in the case in the RCT) would reduce costs and increase net benefits, suggesting E-MAT$_{VR}$ could be considered cost-effective in the future.

This analysis uses results from a feasibility trial to conduct an early economic evaluation. Such evaluations do rely on small sample sizes with high cost/high variable populations, risking negative outcomes, which some argue could

Table 4 Tobit regressions willingness to pay estimates

	Full sample		Full sample, 95% inliers		Positive values only		Positive values only, 95% inliers	
	WTP E-MAT$_{VR}$ Coefficient Std error	WTP E-MAT$_{E}$ Coefficient Std error	WTP E-MAT$_{VR}$ Coefficient Std error	WTP E-MAT$_{E}$ Coefficient Std error	WTP E-MAT$_{VR}$ Coefficient Std error	WTP E-MAT$_{E}$ Coefficient Std error	WTP E-MAT$_{VR}$ Coefficient Std error	WTP E-MAT$_{E}$ Coefficient Std error
Age	− 0.806	− 0.501	− 0.147	− 0.241	− 1.640	− 0.788	− 0.628	− 0.403
	− 0.735	− 0.369	− 0.353	− 0.297	− 0.893	− 0.445	− 0.401	− 0.356
Player	− 17.034	− 12.995*	− 3.657	− 6.297	− 21.901	− 17.070*	− 6.709	− 9.136
	− 12.671	− 6.354	− 6.166	− 5.178	− 16.064	− 8.014	− 7.260	− 6.448
Irish	− 32.757	− 38.666*	− 35.417*	− 41.585**	− 37.018	− 37.388*	− 37.004*	− 39.771**
	− 31.959	− 16.026	− 15.228	− 12.789	− 34.408	− 17.166	− 15.193	− 13.494
Single	6.056	0.443	5.782	2.416	6.647	1.709	6.767	4.196
	− 8.350	− 4.187	− 4.049	− 3.400	− 11.029	− 5.502	− 4.948	− 4.395
Third level education	− 13.000	− 9.684	0.867	− 2.561	− 18.200	− 9.861	0.256	− 1.046
	− 10.307	− 5.169	− 5.086	− 4.271	− 12.711	− 6.342	− 5.845	− 5.192
History testicular disease	7.540	− 0.393	10.806	− 1.930	14.302	2.061	15.338	1.041
	− 22.662	− 11.364	− 10.828	− 9.094	− 35.958	− 17.940	− 15.861	− 14.087
Perceived risk	2.538	− 0.993	− 4.332	− 0.251	4.994	− 5.659	− 4.285	− 0.858
	− 8.052	− 4.038	− 3.945	− 3.930	− 10.036	− 6.309	− 4.606	− 5.072
Student	− 12.246	− 3.390	− 1.152	− 0.846	− 26.373*	− 1.644	− 8.037	− 1.363
	− 9.722	− 4.875	− 4.679	− 3.313	− 12.645	− 5.007	− 5.711	− 4.091
Intercept	100.868 *	83.236**	56.023*	63.878**	145.272*	96.897**	79.255**	70.008**
	− 47.483	− 23.811	− 22.881	− 19.216	− 54.911	− 27.396	− 24.743	− 21.976
Regression variance	910.667	229.008	206.253	145.471	1038.189	258.411	201.814	159.205
	− 149.713	− 37.649	− 34.617	− 24.415	− 197.975	− 49.277	− 39.579	− 31.223
n	74	74	71	71	55	55	52	52

Explanatory variables: Age in years, binary variables: role in GAA, 1 = player, 0 other (e.g., coach); nationality, 1= Irish, 0 otherwise; marital status, 1 = single, 0 otherwise; education, 1 = third level, 0 less than third level; history of testicular disease (yes, no), perceived risk of testicular disease (yes, no) occupation, 1= student, 0 other

n number of observations

**$p < 0.01$, *$p < 0.05$

Table 5 Costs per participant for the delivery of the E-MAT virtual reality intervention compared with the comparator

	E-MAT$_{VR}$ (intervention) (€)	E-MAT$_{E}$ (comparator) (€)
Intervention provision		
Capital costs	79.06	0.35
Delivery costs	25.02	22.40
Sub-total	104.09	22.75
Healthcare resource use	24.92	4.31
Total	129.01	27.06

jeopardize future applications for RCTs in otherwise clinically effective interventions [28]. Despite these limitations, economic evaluations conducted alongside feasibility studies can help develop or refine service plans and outcome measures for RCTs [29]. They can be a cost-effective means of determining whether an RCT is feasible, thereby avoiding inefficient and costly studies/trials on interventions that are unlikely to be considered cost-effective [30, 31]. Therefore, iterative and early economic evaluations can yield efficiency savings by increasing the speed of decision-making, reducing uncertainty around cost-effectiveness estimates [29], and ensuring all eventualities are considered before the main trial begins [30]. This early cost–benefit analysis of E-MAT$_{VR}$ compared with E-MAT$_{E}$ demonstrates that the intervention cannot be considered cost-effective in its current form. A RCT should consider alternative delivery modifications to reduce costs and to determine whether WTP estimates remain constant.

Digital health interventions are increasingly used in public health initiatives and can be useful to capture traditionally hard-to-reach audiences, such as young adult men. However,

Table 6 Cost–benefit analysis and scenario analyses for the E-MAT virtual reality and comparator interventions

	Intervention	€	Net benefit €
Base case[a]			
Mean cost	E-MAT$_{VR}$	104.09	
	E-MAT$_{E}$	22.75	
Mean benefit	E-MAT$_{VR}$	21.88	−82.21
	E-MAT$_{E}$	11.16	−11.59
Median benefit	E-MAT$_{VR}$	10.00	−94.09
	E-MAT$_{E}$	5.00	−17.75
Scenario analysis: 1. Including healthcare resource use costs[b]			
Mean cost (€)	E-MAT$_{VR}$	129.01	
	E-MAT$_{E}$	27.06	
Mean benefit	E-MAT$_{VR}$	21.88	−107.13
	E-MAT$_{E}$	11.16	−15.90
Median benefit	E-MAT$_{VR}$	10.00	−119.01
	E-MAT$_{E}$	5.00	−22.06
Scenario analysis: 2. Delivery costs only[c]			
Mean cost (€)	E-MAT$_{VR}$	25.02	
	E-MAT$_{E}$	22.40	
Mean benefit	E-MAT$_{VR}$	21.88	−3.14
	E-MAT$_{E}$	11.16	−11.24
Median benefit	E-MAT$_{VR}$	10.00	−15.02
	E-MAT$_{E}$	5.00	−17.40
Scenario analysis: 3. Alternative delivery: one visit per club[d]			
Mean cost	E-MAT$_{VR}$	17.57	
	E-MAT$_{E}$	13.92	
Mean benefit	E-MAT$_{VR}$	21.88	4.31
	E-MAT$_{E}$	11.16	−2.76
Median benefit	E-MAT$_{VR}$	10.00	−7.57
	E-MAT$_{E}$	5.00	−8.92

[a]Includes direct costs from healthcare provider perspective (including intervention development)

[b]Cost from base case plus healthcare resource use costs

[c]Intervention development costs excluded

[d]Reduced delivery costs owing to alternative delivery strategy with single coordinated visit (nine clubs and average four participants per club). Excluding intervention development and healthcare resource use costs

as this study shows, digital interventions have high fixed costs associated with their development [32]. Traditionally dismissed as a sunk cost, they have an associated opportunity cost. Given the limited resources available for research on developing and implementing public health interventions, acknowledging and estimating intervention development costs are important and can inform future research priority-setting and resource allocation decisions. Here, when including capital costs, negative net benefit increased. However, in a RCT intervention, costs would be averaged across greater patient numbers, as explored in the sensitivity and breakeven analyses.

In addition, regarding costs, feasibility studies can provide an opportunity to examine the resource use associated with an intervention and savings or other service use impacts [28, 30]. Here, there were only four responses to the resource use questionnaire, as respondents were advised to skip that question if it did not apply. The low response here may not be surprising given the short follow-up time frame and high educational attainment among the group (85% had third level education) [33]. However, to ensure that blank responses correspond to "zero" use, future iterations should include a compulsory question to clarify. Here the follow-up period is short given the feasibility nature of the trial, which reduces the time horizon considered. Any potential savings (accruing from early detection, for example) would be in the longer term. Future economic evaluations, for example, using data from a RCT, could contribute to decision analytical modeling to investigate potential long-term savings from an early intervention. It was beyond the scope of the feasibility study to consider this (from both power and time horizon perspectives). Nevertheless, results of the sensitivity analysis do illustrate how varying perspective, the scope of costs included, and modifications to intervention delivery impact expected net benefit and probability of being cost-effective. These inform future trial design and associated Health Economics Analysis Plans (HEAP).

This early economic evaluation estimated expected benefits using WTP to conduct the cost–benefit analysis. We acknowledge there are some limitations around the approach and sample. While the homogenous sample is ethnically representative of the GAA population, there is a lack of diversity in the sample (which is discussed in full in the process evaluation [6]). To consider the value of the intervention beyond this group, a more diverse sample of men, in more heterogenous environments, is warranted. This may improve the external validity of the WTP results.

We acknowledge that the WTP analysis only employed open-ended questions, which have no upper and lower bounds (contributing to lower internal validity). While routinely adopted in the digital health literature [15, 17], we acknowledge there are limitations with its use, which are evidenced in the distribution of the data, which is skewed. In addition, the order of the WTP questions were not varied to determine whether the order impacted results. Unfortunately, the process evaluation conducted for the feasibility study [6] did not explicitly examine experiences with the WTP questions, which was a missed opportunity. This is worth considering in a future RCT.

We did include explicit information on risk perception, which was not statistically significant in the regression analyses. Given the profile of the participants (GAA players and coaches) they would be susceptible to testicular injury and consequent disease [5, 6]. The low overall perceived risk of testicular diseases is a barrier to early help-seeking for

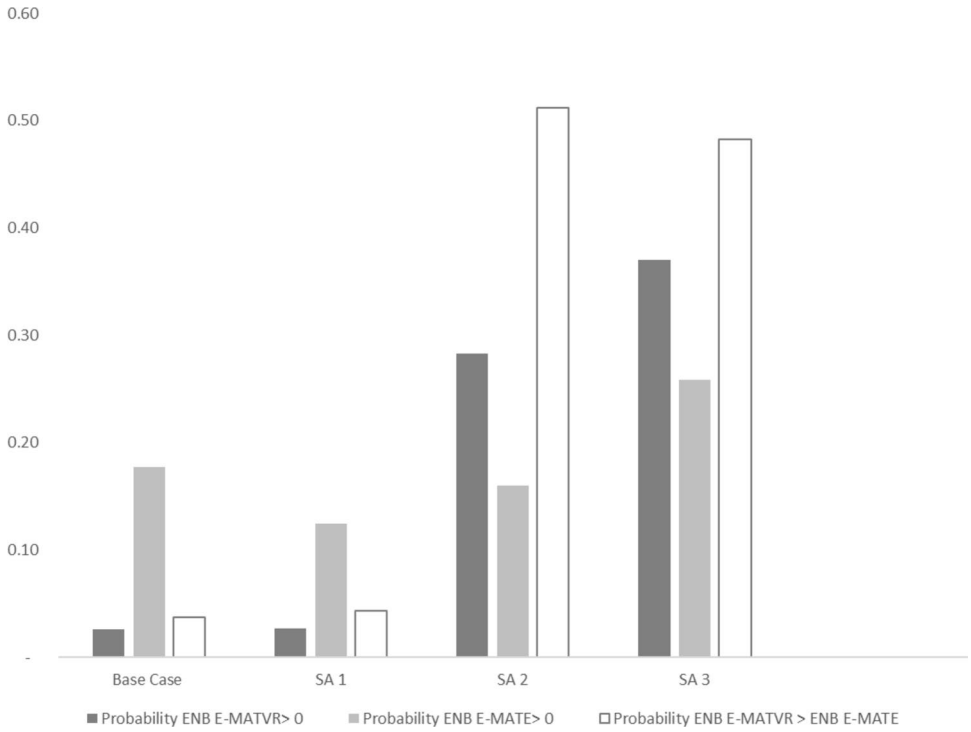

Fig. 2 Summary of probabilistic sensitivity analysis results for the E-MAT virtual reality and comparator interventions. *ENB* expected net benefit. Scenario Analysis: 1. Including Healthcare Resource Use Costs. Scenario Analysis: 2. Delivery Costs Only. Scenario Analysis: 3. Alternative Delivery: One visit per club. See Supplementary Table A3

cancer symptoms among men. One explanation is that testicular diseases are often diagnosed in younger men who are relatively healthy and who have limited to no contact with the healthcare system [5]. In addition, two of the 74 participants reported a personal history of testicular disease. These were not statistically significant in the regression analyses. As discussed in the process evaluation of the feasibility study [6], inclusion of participants who have a personal and/or family history of testicular disease ought to be considered in the design of a future RCT.

Albeit the small sample, the WTP data collected here had a high response rate, suggesting it would be feasible to collect in a full RCT. We acknowledge that subjectivity and context bias, as well as the role of income, are limitations when using this type of measurement, as may be the case with this restricted sample. There is also a risk that reported WTP preferences, when part of a survey, might not truly reflect real-life behaviors, causing external invalidity. Consequently, CVM can yield hypothetical inflated responses with scope and nesting effects [34]. Nevertheless, the high absolute values are consistent with previous literature that younger, higher-income, male individuals are willing to pay more for digital services [35]. Overall, without a market for the intervention, CVM was suitable for collecting WTP estimates, allowing a direct valuation suitable for a cost–benefit analysis. This gives an understanding of what participants value in future health services. In theory, the costs and effects observed in a feasibility study can also be used in value of information analysis to explicitly examine whether the cost of a RCT is worthwhile [28]. However, as an expected difference in quality of life was not expected between the two groups, utility data were not collected to facilitate a value of information analysis here.

5 Conclusions

Despite the rapid growth of digital health interventions, evidence on their cost-effectiveness is scarce. This early economic evaluation provides information to inform and support future research design decisions for RCTs and implementation of a digital health intervention raising awareness of testicular diseases and promoting self-examination and early help-seeking among young men. The data collection methods were generally fit for purpose and response rates were high. Nevertheless, as delivered in the feasibility trial, E-MAT$_{VR}$ is not considered cost-beneficial. Scenario analyses demonstrate how delivery modifications to reduce costs could improve the likelihood of E-MAT$_{VR}$ being considered cost-effective.

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Declarations

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Code availability statement The code for analyzing the dataset are available in the Open Science Framework (OSF) repository, https://osf.io/m5wb7/. Code for cost–benefit analysis available from authors upon request.

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Consent to participate Written informed consent for participation was obtained from all participants as per the ethical approval (ECM 06/2023 PUB).

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