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RESEARCH ARTICLE

Monitoring chronic heart failure: Adaptive choice-based conjoint analysis to elicit individual level patients' preferences

[Surveillance de l'insuffisance cardiaque chronique: analyse conjointe adaptative basée sur le choix pour déterminer les préférences individuelles des patients]

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Abstract: Chronic heart failure (CHF) patients are facing trade-offs when deciding on the use of medical devices to monitor hemodynamics/changes in pulmonary artery pressure, indicating a worsening. This study assessed individual level patients' preferences for benefits and risks of CHF monitoring. A systematic literature search and pre-test interviews were conducted to determine the relative importance of patient-relevant endpoints in terms of benefits, risks, and administration of CHF treatments. An adaptive choice-based conjoint (ACBC) was applied in a survey where respondents were assisted by interviewers. Treatment profiles in the choice scenarios included the attributes of mobility, mortality risk, risk of hospitalization, type and frequency of monitoring, and risk of medical device and system relevant complications. The ACBC was divided into different sections: build-your-own (BYO) configurator, screening section, and choice-based conjoint tasks. Each respondent was required to answer a set of questions in each section, with the content depending on the information given in the preceding questions. Data was analyzed using a hierarchical bayes (HB) model. Results of the ACBC analysis showed that heart failure patients gave the highest importance to the risk of death attribute. In second and third places were the risk of hospitalization and mobility. These results can be confirmed by a previously published random parameter logit (RPL) model based on a traditional discrete choice experiment (DCE). Patients rated low risk of death and low risk of hospitalization higher than the other attribute levels in the decision context of this study. Higher risks of death and hospitalization would have a significant impact on patients' decisions to choose an alternate option treatment. The type and frequency of monitoring was less important. The different HB models also showed that the model with excluded BYO section performed best. To conclude, the ACBC analysis confirmed the results of a previously published RPL model for a DCE.

Keywords: Heart failure Treatment; Monitoring pulmonary artery pressure; Health Preference; Adaptive choice-based conjoint.

Résumé : Les patients souffrant d'insuffisance cardiaque chronique (ICC) sont confrontés à des compromis lorsqu'ils décident d'utiliser des dispositifs médicaux pour surveiller l'hémodynamique/changements de pression de l'artère pulmonaire, indiquant une aggravation. Cette étude évalue les préférences des patients au niveau individuel pour les avantages et les risques de la surveillance de l'ICC. Une recherche documentaire systématique et des entretiens préalables ont été menés pour déterminer l'importance relative des critères d'évaluation pertinents pour le patient en termes d'avantages, de risques et d'administration des traitements de l'ICC. Une méthode conjointe adaptative basée sur le choix (ACBC) a été appliquée dans le cadre d'une enquête où les répondants étaient assistés par des intervieweurs. Les profils de traitement dans les scénarios de choix comprenaient les attributs de mobilité, risque de mortalité, risque d'hospitalisation, type et fréquence de la surveillance, et risque de complications liées aux dispositifs médicaux et aux systèmes. L'ACBC a été divisé en différentes sections : le configurateur BYO (build-your-own), la section de dépistage et les tâches conjointes basées sur le choix. Chaque répondant devait répondre à une série de questions dans chaque section, dont le contenu dépendait des informations fournies dans les questions précédentes. Les données ont été analysées à l'aide d'un modèle hiérarchique bayésien (HB). Les résultats de l'ACBC montrent que les patients souffrant d'ICC attachent une plus grande importance à l'attribut de risque de décès. En deuxième et troisième positions se trouvent le risque d'hospitalisation et la mobilité. Ces résultats peuvent être confirmés par un modèle logit à paramètres aléatoires (RPL) publié précédemment et basé sur une expérience traditionnelle de choix discret (DCE). Dans le contexte décisionnel de cette étude, les patients ont accordé une note plus élevée au risque faible de décès et au risque faible d'hospitalisation qu'aux autres niveaux d'attributs. Des risques plus élevés de décès et d'hospitalisation auraient un impact significatif sur la décision des patients de choisir une autre option de traitement. Le type et la fréquence de la surveillance étaient moins importants. Les différents modèles HB ont également montré que le modèle avec la section BYO exclue était le plus performant. En conclusion, l'ACBC confirme les résultats d'une étude précédemment publiée basée sur un modèle RPL pour un DCE.

Mots clés : Traitement de l'insuffisance cardiaque; Surveillance de la pression de l'artère pulmonaire; Préférence en santé; Analyse conjointe adaptative basée sur le choix.

Introduction

Innovative methods exist for monitoring patients with chronic heart failure (CHF) that allow electronic transmission of physiological data using remote access technology via wireless implantable electronic devices. This enables continuous monitoring of physiological parameters associated with heart failure [1]. Patients with CHF must perform trade-offs among benefits and risks when deciding whether to implant a monitoring system. This study assessed individual level patients' preferences for benefits and risks of CHF monitoring. In this aim, it identified, ranked and weighted patient-relevant endpoints of monitoring options for CHF. Patient preference information (PPI) can improve treatment decisions and thus treatment outcomes to make CHF treatments more patient-centered in the future. This analysis complements two previous studies using a random parameter logit (RPL) model and a latent class analysis (LCA) [2,3].

Methods

Attributes and levels

Individuals make complex decisions, especially in healthcare. The aim of this study was to analyze the preferences of CHF patients for the implementation of a monitoring system. The “treatment” in this case encompasses rather a monitoring than actual therapy. Consequently, the attributes used refer to place and frequency of monitoring in terms of comparing an implantable (home-based) device to a standard regular check at the physician office. To determine patient-relevant attributes and levels for the best-worst scaling (BWS) survey, a literature review and qualitative pre-test interviews were conducted to describe the benefits and risks of an innovative implantable monitoring system. Development of the questionnaire and identification of attributes and levels for the BWS was based on qualitative pre-test interviews conducted with patients in June 2018 in Germany.

The research objective of the study was an innovative implantable monitoring device. This should replace repeated visits to the cardiologist to check general values related to the heart failure on a regular basis (progress controls, not acute treatment). Hence, the following attributes were derived from the literature:

- Monitoring frequencies: a normal HF patient has regular appointments at his/her doctor about every 6 weeks. This is depicted be the frequency of 9x. With the implanted device, pressure, pulse etc. are recorded every week, hence 56x / year. To have a linear level set 32x was set as third level.

- level range for mobility: the level range for this attribute was taken from the commonly used 6-minute walking test. This test is a standard assessment tool in heart failure.
- Risks of death, hospitalizations, or complications: all level ranges were taken from clinical studies on either regular checkups and progress controls or implantable and other devices for the monitoring of heart failure.

Choice-based conjoint analysis

The choice-based conjoint (CBC) analysis, also known as discrete choice experiment (DCE), is the most widely used preference elicitation method. Due to limitations of the standard DCE, e.g., the lack of focus on certain levels of critical attributes that are absolutely necessary for respondents (e.g., must have features), the adaptive choice-based conjoint (ACBC) analysis was introduced in 2007 [4]. Nevertheless, the ACBC approach has been used less frequently in recent years compared to standard DCE [5]. A unsystematic PubMed search for the use of ACBC with the term ''Adaptive Choice-Based Conjoint'' resulted in only few publications in the last 10 years. In contrast to the standard DCE, this may be due to the more complex design, the more challenging implementation and realization in the survey and the limited analysis possibilities of standard softwares.

However, the low frequency of use seems to be limited to the academic field. In contrast, “commercial” practitioners used the ACBC approach more frequently. An annual report on conjoint analysis use among Sawtooth Software customers showed that 34% of users reported that their company had used ACBC during the last 12 months and the percentage of total conjoint analysis projects among users that employed ACBC was 14% (data collected on April-May 2020) [6]. This makes ACBC alongside the standard DCE and MaxDiff Analysis, also known as BWS, one of the most widely used methods among practitioners.

In contrast to standard CBC, in adaptive methods such as ACBC, respondents are asked in advance which attributes are most important for their choice decisions, and only these attributes are included in the conjoint exercise. This approach attempts to overcome the various limitations of the standard CBC, e.g., product concepts are not close to the respondent’s ideal, respondents rush through choice tasks without giving thoughtful responses, survey experience is seen as repetitive and boring, and critical attributes are underrepresented in a CBC survey [4]. ACBC helps simplify the scope of decision making by providing a consideration set of preferred attribute levels. Follow-up decisions on preferred treatment alternatives are then made specifically on that basis. Even in simplified choice decisions, individuals do not make perfect decisions, either because decisions are made randomly or because of misunderstood or misleadingly formulated questions in the survey.

To our knowledge, this is the first study to use the ACBC method, rather than a DCE [7], to examine trade-offs between the benefits and risks of a therapy for patients with CHF.

The ACBC approach was designed to provide a survey process that is more engaging for respondents, to obtain more information at the individual level than traditional CBC, to capture more accurate data, and to better predict real-world preferences [8]. The aim of the ACBC is to combine the advantages of traditional CBC with ACBC and to minimize its disadvantages. For this purpose, the method considers the answers of the respondents during the survey. The ACBC is divided into different sections, with the content depending on the information given in the preceding questions:

- Build-your-own (BYO) configurator;
- Screening section;
- Choice-based conjoint tasks.

The ACBC can still be adapted in detail. An additional part to evaluate the none-parameter or to estimate purchase probabilities of individual alternatives can be added. Individual parts, that is, not necessarily needed sections, can be left out. For example, the BYO section could be skipped if the levels of all attributes have an objectively clear rank order. However, the main part of the ACBC is defined by these three sections [8,9].

Build your own

The first section introduces the attributes and levels, with respondents indicating their preferred level for each attribute. This means that each respondent compiles his or her preferred product from the predefined levels. Based on the answers to this section, a relevant pool of concepts will be created in which the attribute levels are relatively concentrated (oversampled) on the respondents' preferred attribute levels [8,9].

Figure 1 shows the BYO as it was presented to the respondents in the survey for monitoring CHF. Each attribute was displayed with the corresponding levels. The participants were asked which level they would prefer for each attribute. Depending on which level the participants chose, the corresponding graphic for the selected attribute level was displayed on the right side. The individual graphics in combination described the perfect alternative for the participant.

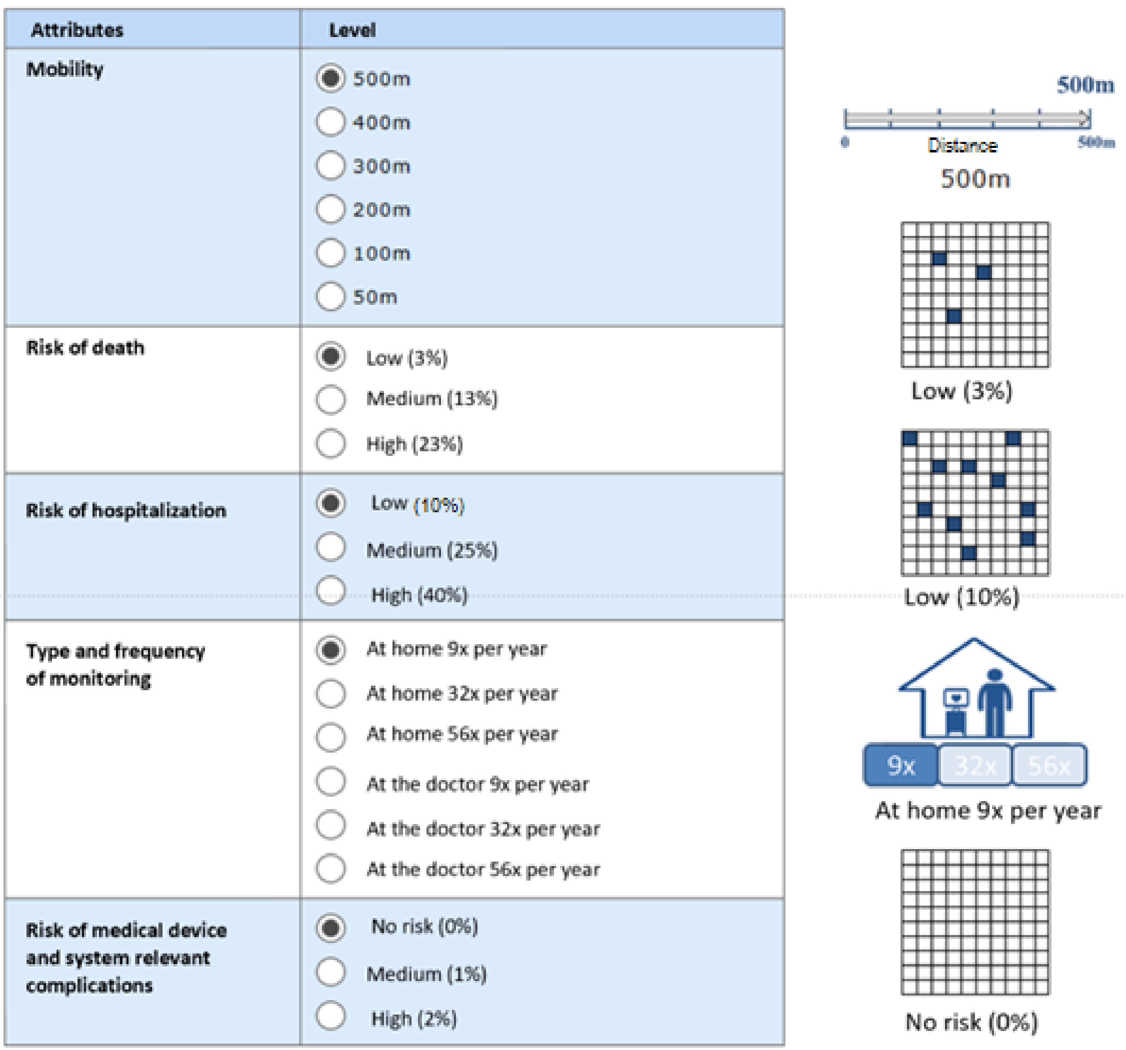

Figure 1. Build-your-own section of the ACBC in the survey: Respondents specify the preferred levels for each attribute

Screening section

The previously compiled product is used as the basis for the design of the concepts, respectively alternatives or option. In the screening section respondents are shown a set of alternatives clustering around the preferences expressed in the BYO section. The alternatives are shown in full profile, that is, a concept is defined by one level of each attribute of the survey. Respondents are asked to indicate whether they would consider each of the alternatives as possible option of monitoring for them or not. Concepts marked as possible are included in the subsequent CBC tasks [8,9].

Over a series of screening questions, attributes that each respondent included or excluded from concepts selected as possibilities are identified. Respondents are shown a list of attribute levels and asked to determine which attribute levels they would and would not accept. Respondents are explicitly asked again whether certain attribute levels really have to be present or not. Over a series of screening questions, a threshold for necessary levels (must haves) or unnecessary levels (unacceptable) can then be identified. This information is taken into account in the design of the concepts and also used in the subsequent section [8,9]. The corresponding question in the survey was: “Please indicate for each characteristic which level you would choose!”. A failure in the BYO section does not lead to useless follow-up sections in the ACBC. Illogical answers can be corrected.

In the survey, four options of monitoring were repeatedly presented to the respondents in the section (Figure 2). The design of the therapies was mainly based on the attribute levels previously chosen by the participants as their preferred ones. Nevertheless, all attribute levels, including the non-preferred ones, were considered in the set of all presented therapies. The focus, however, was on the preferred levels. The respondents were then asked to decide for each therapy whether they would choose it or not.

Depending on the respondents' answers, individual requests for unacceptable and necessary attribute levels were made between the screening questions. The respondents can then select the level that is unacceptable or necessary. Based on this, follow-up questions ask about further unacceptable levels for the respondents. There are also questions about absolutely necessary levels (see supplementary file).

Choice-based conjoint tasks

After finishing the screening section, the respondents completed a standard CBC. In this section, the difference to a standard DCE approach is that the alternatives/concepts presented in small sets depend on the selection process in the previous sections. Each chosen alternative (or concept) from a choice set advances to the next set, where it competes with other alternatives/concepts derived from the previous screening section. The last chosen concept is then identified as the winner [8,9]. However, the goal of this section is not the identification of an overall winning concept. The actual goal is to engage respondents a CBC-looking exercise that leads to good trade-off data for estimating part worth utilities [8].

In this section of the survey, the respondents were repeatedly presented three alternatives (Figure 3). The individual sets were composed of the therapies previously selected as an option. The respondents were asked to choose the best therapy. For comparison, the levels that were identical across all therapies shown were greyed out. This allowed the respondents to focus their choices only on the differences between the therapies.

In total, respondents had to complete 14 choice tasks. The additional choice tasks were excluded from the statistical model analysis. Attributes were randomized once for each respondent to control for order effects across respondents.

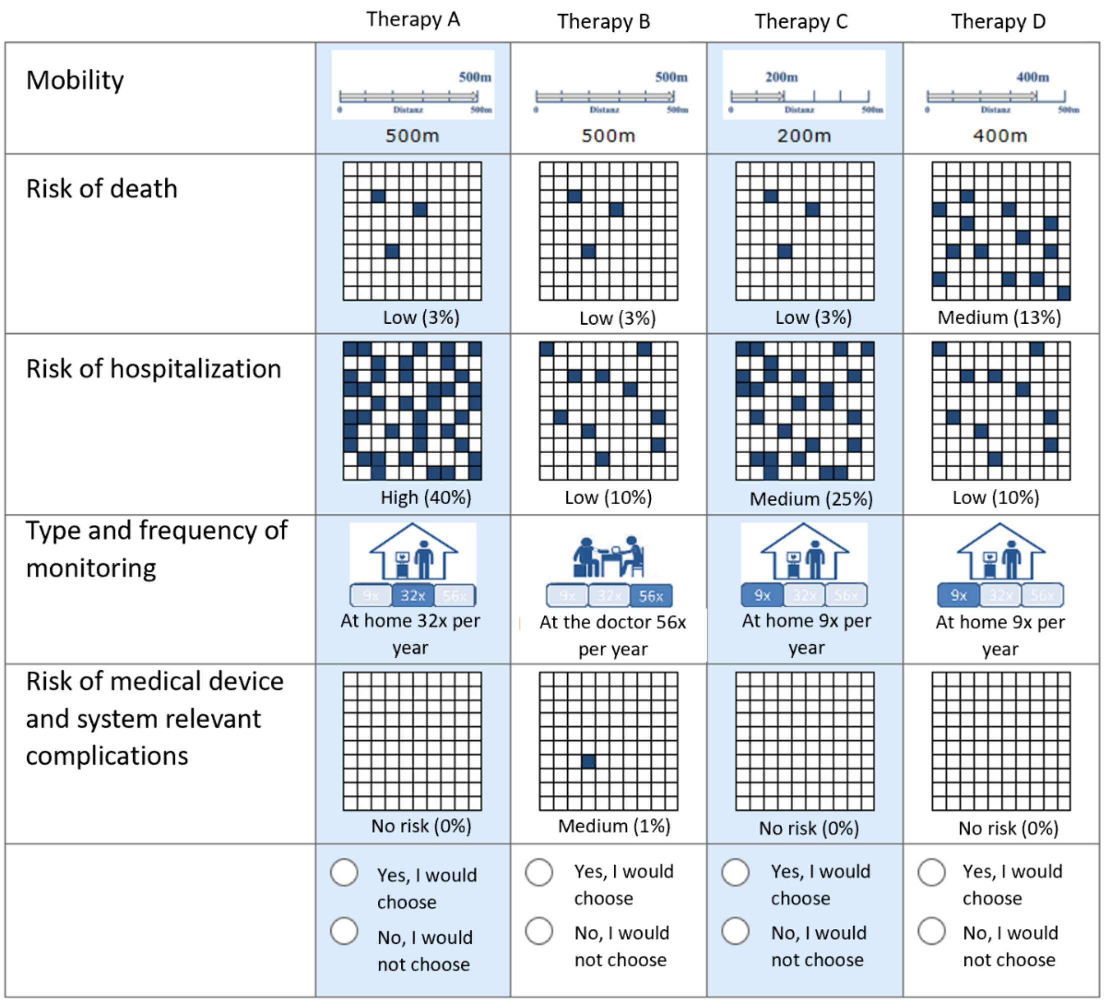

Figure 2. Example of the screening section of the ACBC: Questions about the acceptance of therapy alternatives

Recruitment

The study population included German patients with NYHA class 3 heart failure, recruited with the help of an external market research company. The referral was made via the treating physicians. No quotas were used except for age (>18) and classification into NYHA class. The participants had to have good to very good German language skills and give their consent to participate in the study. The survey was conducted between October 2019 and August 2020.

Analysis and survey development

Preference data from each step of an ACBC survey can be analyzed individually or in combination, e.g., using multinomial logit models or hierarchical bayes models [8,9]. The survey was developed using Lighthouse Studio by Sawtooth Software (Version 9.10.1) [10] and Stata 16 (Stata Corp., TX, USA) was used for analysis.

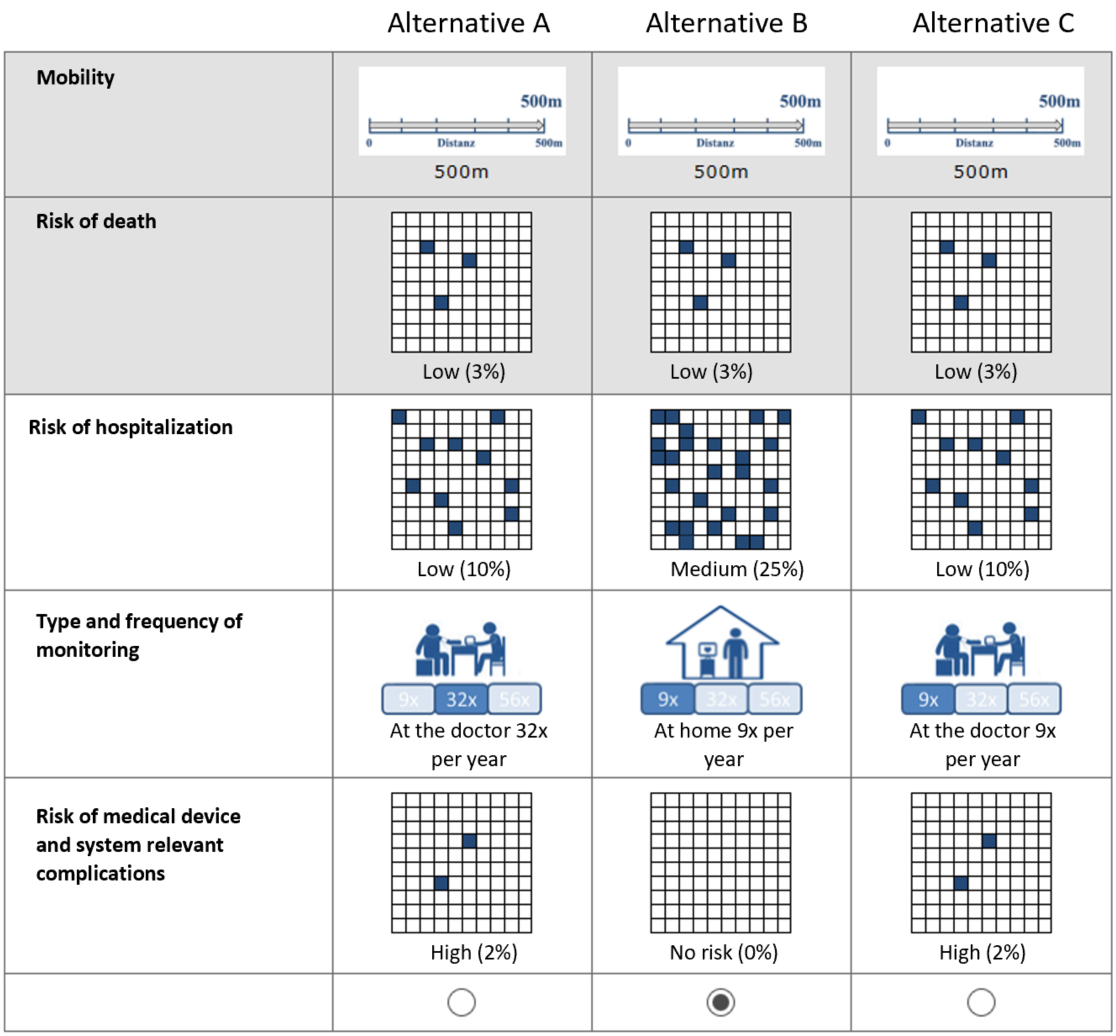

Figure 3. Choice-based conjoint tasks of the ACBC: Classical CBC with previously accepted alternatives

Results

Prior to conducting the BWS a comprehensive literature review was conducted to identify possible attributes (and levels) to describe the benefits and risks of an innovative implantable monitoring system. Five attributes were identified as relevant for this study. The respondents (N=278) had to indicate their preferred attribute levels in terms of mobility, risk of death, risk of hospitalization, type and frequency of monitoring, and risk of medical device and system related complications.

Build your own: Counts analysis

Table 1 presents the attributes together with their corresponding levels, and the answers of the respondents to the BYO section.

71.22% (n=198) of respondents indicated that they would prefer to be able to walk a distance of 500m, while the remaining respondents preferred a walking distance of less than 500m. At this point, however, it is also noticeable that many respondents nevertheless chose a distance of less than 500m, some even shorter distances with 100m (2.52%; n=7) and even only 50m (1.08%; n=3).

Regarding the second attribute, the majority of the respondents (73.74%; n=205) preferred a low risk of death. Similar to the first attribute, the question can be raised as to why respondents should select a higher risk.

Table 1. Attributes and levels used in the ACBC survey and frequency distribution in the BYO section (sample size = 278)

Attribute	Level	Frequency	Percent
Mobility	500m	198	71.22
	400m	38	13.67
	300m	25	8.99
	200m	7	2.52
	100m	7	2.52
	50m	3	1.08
Risk of death	Low (3%)	205	73.74
	Medium (13%)	63	22.66
	High (23%)	10	3.60
Risk of hospitalization	Low (10%)	205	73.74
	Medium (25%)	65	23.38
	High (40%)	8	2.88
Type and frequency of monitoring	At home 9x per year	49	17.63
	At home 32x per year	24	8.63
	At home 56x per year	18	6.47
	At the doctor 9x per year	169	60.79
	At the doctor 32x per year	18	6.47
	At the doctor 56x per year	0	0
Risk of medical device and system relevant complications	No risk (0%)	141	50.72
	Mild (1%)	108	38.85
	High (2%)	29	10.43

Similarly, for the attribute of risk of hospitalization, the majority preferred (73.74%; n=205) a low risk, while the remaining respondents selected a medium or even a high risk of hospitalization.

The attribute type and frequency of monitoring is composed of two dimensions: place (type) of monitoring, and frequency of monitoring. Most of the respondents would prefer to be monitored at the doctor's place (67%; n=187). Regarding the frequency of visits at the doctor, a lower number of 9 times per year (60.79%; n=169) is preferred by the respondents to a more frequent number of 32 times per year (6.47%; n=18). None of the respondents had an interest to visit a doctor for monitoring 56 times per year. In contrast, only one third of the respondents (33%; n=91) would prefer monitoring via a sensor from home. In terms of frequency of monitoring, a lower frequency is also more preferred than a more frequent one. Forty-nine respondents (17.63%) opted for monitoring 9 times per year, 24 respondents (8.63%) for monitoring 32 times per year, and 18 respondents (6.47%) for monitoring 56 times per year.

A few respondents (10.43%; n=29) chose the objectively worst level (high risk of 2%) for the last attribute risk of complications. Similarly, a larger number of respondents (38.85%; n=108) chose the second highest risk (mild risk of 1%). Only about half of the respondents (50.72%; n=141) chose the best level (no risk).

Some of the answers suggest irrational decision-making behavior by the respondents. It remains unclear why an objectively worse level, e.g., high risk, should be preferred to a better level, e.g., low risk. It might be possible that respondents misunderstood or misinterpreted the question. The corresponding question in the survey might be wrongly interpreted since trade-off would be expected according to respondents' real expectations and experiences. Regarding mobility, perhaps some respondents have indicated a necessary distance of their daily routine where a distance to be covered on foot might be less than 500m. For the risk attributes (risk of death, risk of hospitalization, and risk of medical device and system relevant complications), respondents may have assessed their own individual needs based on their realistic assumptions.

When looking at the raw data, it is striking that seemingly only a third of the respondents made rational decisions on this task (33%; n=93), i.e., for the attribute mobility as well as the risk attributes, the objectively best level was chosen. It might also be possible that for some respondents, covering a distance of 500 meters is not necessary in everyday life. If only those respondents are considered who have chosen the best level for each risk attribute, the number of respondents increases (40%; n=110). However, which decision patterns the remaining respondents applied or how they understood the task in this section still have to be evaluated.

Screening section: Counts analysis

As a reminder, in this section the respondents were repeatedly presented with different treatment alternatives, which they can agree or reject. All attribute levels were considered in the design of the alternatives. However, the focus was on the levels previously selected by respondents. The selected alternatives were then transferred to the next section.

Each respondent was presented 8 screening tasks with 4 concepts (in this case, treatment alternatives) per task. For a total of 32 concepts, respectively alternatives, respondents had to decide whether they would be a realistic preferred treatment alternative. Of a total of 8896 alternatives across all respondents (278 respondents x 32 alternatives), 2802 alternatives (31%) were selected as "possibility". Most respondents (n=163) marked 8 concepts/alternatives as a realistic choice possibility (Figure 4). These concepts were then forwarded individually for each respondent to the next section.

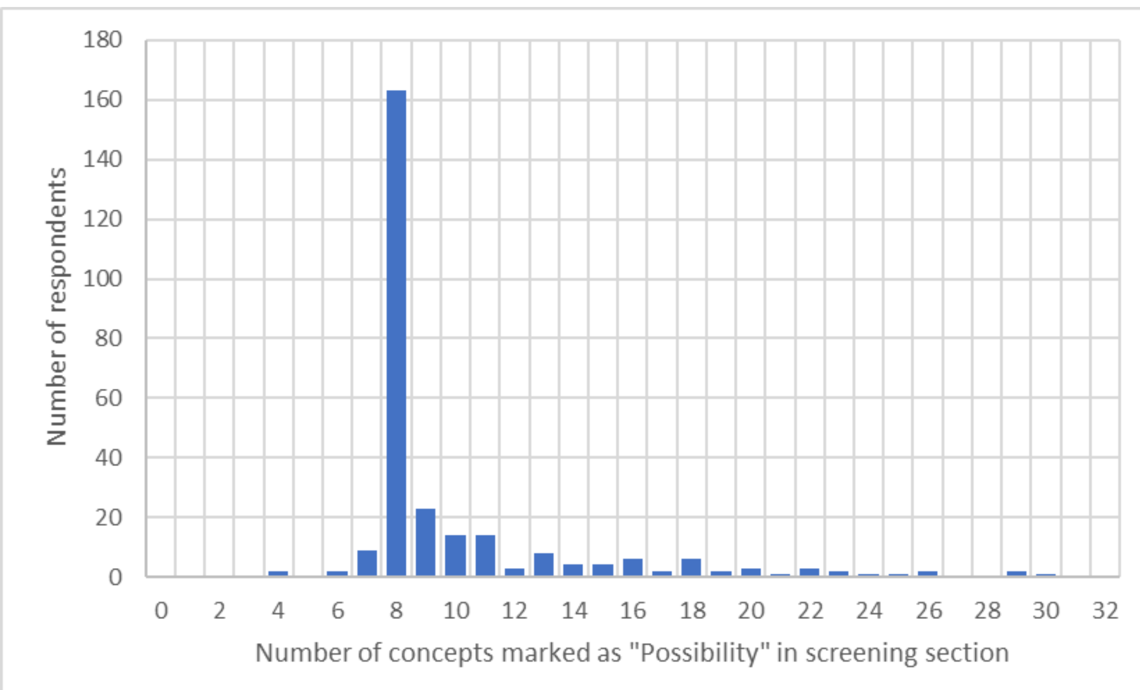

Figure 4. Number of concepts marked as "Possibility" in screening section

In between, depending on the respondent's decision during the screening section, the respondents were asked about the acceptance (must have) or non-acceptance (unacceptable) of some attribute levels. The number of "must have" questions in the screening section was 2, and the number of "unacceptable" questions was 3 per respondent.

In the screening section, 49.28% (n=137) indicated a mobility of 50m as unacceptable (Table 2). The percentages of the levels of an attribute can be more than 100 percent because multiple answers were possible, i.e., a respondent was repeatedly asked about the level of an attribute. In contrast, only 3.96% (n=11) regarded a mobility of 500m as a must-have-level (Table 2). The threshold of mobility for a preferred or required distance seems to be between 100m and 500m. Regarding risk of death, for 32.73% (n=91) of the respondents, a low risk of death was a must-have-level a therapy. For 69.06% (n=192) of the respondents, a high risk of death was unacceptable in a therapy. In contrast, a low risk of hospitalization was a must-have-level for only 18.35% (n=51). A high risk was unacceptable for about half of the respondents (48.92%; n=136). Respondents were less frequently asked whether there was a must-have level of the attribute type and frequency of monitoring. However, 39.93% (n=111) of the respondents stated that visiting a doctor's office 56 times per year was unacceptable. As for the attribute risk of medical device and system relevant complications, 22.66% (n=63) indicated a high risk as unacceptable. Only 2.16% (n=6) regarded no risk as a must-have-level.

Table 2. Must have and unacceptable report from screener section

		Must have		**Unacceptable**	
Attribute	**Level**	**N**	**%**	**N**	**%**
Mobility	500m	11	3.96	0	0
	400m	22	7.91	11	3.96
	300m	18	6.47	33	11.87
	200m	28	10.07	51	18.35
	100m	58	20.86	79	28.42
	50m	0	0	137	49.28
Risk of death	Low (3%)	91	32.73	0	0
	Medium (13%)	101	36.33	91	32.73
	High (23%)	0	0	192	69.06
Risk of hospitalization	Low (10%)	51	18.35	0	0
	Medium (25%)	85	30.58	51	18.35
	High (40%)	0	0	136	48.92
Type and frequency of monitoring	At home 9x per year	2	0.72	16	5.76
	At home 32x per year	0	0	20	7.19
	At home 56x per year	1	0.36	53	19.06
	At the doctor 9x per year	5	1.8	8	2.88
	At the doctor 32x per year	1	0.36	32	11.51
	At the doctor 56x per year	0	0	111	39.93
Risk of medical device and system relevant complications	No risk (0%)	6	2.16	0	0
	Mild (1%)	57	20.5	6	2.16
	High (2%)	0	0	63	22.66

Regarding the risk attributes, a high risk was unacceptable for most of the respondents, whereas a medium risk, respectively a mild risk, seemed to be a minimum must-have-level in a CHF monitoring. As seen before in the BYO section, the longest distance of 500m does not seem to be the preferred level of mobility for all respondents. Preferences for monitoring also appear to vary between respondents.

Table 3 shows the number of times a given level was used in a concept marked as “Possibility“ across all concepts. The level 500m of mobility was included 4335 times in all chosen concepts. This corresponds to a share of 39.69 percent within the mobility attribute. The level 50m was least often present in the marked concepts (n=882; 8.07%). The levels with the lowest risk of the attributes risk of death and risk of hospitalization were most frequently present in the selected concepts. A low mortality risk was present 6491 times, which is a share of 59.43% within this attribute. A low risk of hospitalization was present 6411 times in the selected corresponding to a share of 58.70%. Monitoring at the doctor's office was somewhat preferred to monitoring at home. The preferred frequency of monitoring was 9 times per year. For the attribute risk of medical device and system relevant complications, the level no risk was most present in the selected concepts (n=4794; 43.89%).

Table 3. Number of times a level was present in a chosen concept in the screening section

Attribute	Level	N	%
Mobility	500m	4335	39.69
	400m	2158	19.76
	300m	1459	13.36
	200m	1080	9.89
	100m	1008	9.23
	50m	882	8.07
Risk of death	Low (3%)	6491	59.43
	Medium (13%)	3126	28.62
	High (23%)	1305	11.95
Risk of hospitalization	Low (10%)	6411	58.70
	Medium (25%)	3182	29.13
	High (40%)	1329	12.17
Type and frequency of monitoring	At home 9x per year	1926	17.63
	At home 32x per year	1508	13.81
	At home 56x per year	1375	12.59
	At the doctor 9x per year	3752	34.35
	At the doctor 32x per year	1362	12.47
	At the doctor 56x per year	999	9.15
Risk of medical device and system relevant complications	No risk (0%)	4794	43.89
	Mild (1%)	4178	38.25
	High (2%)	1950	17.85

Choice-based conjoint tasks: Counts analysis

This section represents a traditional CBC. The choice sets consisted of the alternatives that the respondents had previously selected as a possibility. Depending on the previous answers, the respondents not only had a different number of choice tasks, but also a different number of choice alternatives. However, each choice task contained 3 choice alternatives. Each chosen alternative of a choice set was then transferred to a following choice set. In the end, an individual “winning concept“ was determined for each respondent.

Table 4 shows the counts analysis of the “winning concept“. The frequency indicates how often a level was present in all "winning concepts". Here it becomes apparent that the respondents preferred low risks. Over 90 percent of the winning concepts contained either a low/no risk, or a medium/mild risk. For the attribute risk of death, 91.73% (n=255) of the concepts contained a low risk, for the risk of hospitalization, 82.37% (n=229) contained a low risk, and for the risk of medical device and system relevant complications, only 62.23% (n=173) contained the best level with no risk. Regarding mobility, 94.24% (n=262) of the “winning concepts“ contained a mobility of at least 200m. Most concepts contained 500m mobility (52.52%; n=146). For the attribute type and frequency of monitoring, slightly more “winning concepts“ included monitoring at the doctor's office (53.96%; n=150) than monitoring at home (46.04%; n=128). Monitoring 9 times per year was most frequently included in the concepts. Eighty-one (29.14%) of the concepts included monitoring at home 9 times per year, and 120 concepts (43.17%) included monitoring at the doctor 9 times per year.

Table 4. Composition of "winning concept“ from choice-based conjoint tasks

Attribute	Level	Frequency	Percent
Mobility	500m	146	52.52
	400m	72	25.9
	300m	26	9.35
	200m	18	6.47
	100m	7	2.52
	50m	9	3.24
Risk of death	Low (3%)	255	91.73
	Medium (13%)	17	6.12
	High (23%)	6	2.16
Risk of hospitalization	Low (10%)	229	82.37
	Medium (25%)	38	13.67
	High (40%)	11	3.96
Type and frequency of monitoring	At home 9x per year	81	29.14
	At home 32x per year	35	12.59
	At home 56x per year	12	4.32
	At the doctor 9x per year	120	43.17
	At the doctor 32x per year	22	7.91
	At the doctor 56x per year	8	2.88
Risk of medical device and system relevant complications	No risk (0%)	173	62.23
	Mild (1%)	80	28.78
	High (2%)	25	8.99

Hierarchical bayes estimation

For parameter estimation using the hierarchical bayes (HB) model, data from all ACBC sections can be used. However, the results from the other sections might be excluded from the parameter estimation, depending on the model used. Table 5 shows the zero-centered part-worth utilities of different combinations of ACBC sections: the main CBC section alone and combined with the remaining sections. Models 1 and 2 were excluded for interpretation since respondents seemed to give irrational answers in the BYO section or misunderstood or misinterpreted the task. For the final analysis and interpretation, model 3 was chosen over model 4 because model 3 considered all information from ACBC except the BYO section and model 4 only a portion of the information. Also, the goodness of fit-criteria root likelihood (RLH) indicates model 3 as the better model. Another model (Otter's method) considering differences in scale [8] for the three ACBC sections which shows very similar results to model 3 can be found in the appendix.

The zero-centered part-worth utilities are a normalized transformation of the "raw" utilities which come directly from the HB estimation. The problem with interpreting raw utilities is that the magnitude of raw utilities increases with higher consistency of respondents' answers. The transformation dissolves different magnitude scaling of respondents and makes the raw utilities to have a similar magnitude for each respondent. The raw data is transformed so that the utility distance from the best to the worst level per respondent is 100 on average. The part-worth utilities of the attribute levels are estimated on an aggregated level.

The parameter "None" is the threshold utility from the screening section. It's the utility of the "Not a possibility" selection that respondents made when evaluating each concept in the screening section. The parameter can be used in simulations to estimate the percentage of participants who would not choose any of the presented concepts [4,9]. The part-worth utility of the non-parameter is so large because in the screening section less than half of the presented concepts were chosen as possibilities. The non-parameter is of little importance here and will not be considered further in the following analysis.

A large part-worth utility is equivalent to a high preference of the respondents for an attribute level. The larger the value, the larger the preference for this level. Positive values indicate a preferred level, negative values indicate a non-preferred level. All signs were as expected. Regarding mobility, a longer distance was preferred over a shorter one. Between 300 (9.8) and 200 (-10.1) meters seemed to be a threshold, since the two part-worth utilities cross the null line. On average, a low risk of death (81.5) can be considered as a must in CHFcare. The levels for medium (-11.0) and high risk (-70.5) were not preferred, whereas the high risk was strongly rejected by the respondents. A similar result was obtained for the other risk attributes. The risk of hospitalization was more important for the respondents than the risk of complications. The respondents preferred to be monitored 9 times per year. A monitoring 56 times per year at the doctor (-39.3) was more strongly rejected than a monitoring 56 times per year at home (-17.5). In model 3, none of the confidence intervals included the zero. This means that all levels are significantly different from zero.

Figure 5 shows the boxplots of the individual part-worth utilities of each attribute level. The wide range at level 500m of the mobility attribute indicates a high degree of heterogeneity with a few outliers only at the upper end. Apparently, a mobility of 500 meters is not desirable or necessary for every respondent. In contrast for the level of low risk of death, here the whiskers are shorter, especially on the upper end. The outer 50% of the data are not too far away from the 1st and 3rd quartile, excluding a few outsiders. It can be seen, however, that many single data points are outside the left whisker, which indicates a strong dispersion far outside the median. At this point it can be questioned why (and which) respondents should not prefer a low death risk in CHF care indicated by negative part-worth utilities. The box plot shows five extreme outliers below zero.

Table 5. Part-worth utilities of all attribute levels (rescaled as zero-centered diffs) in the HB estimation

		Model 1 (Sections included: 1,2,3)				**Model 2 (Sections included: 1,3)**				**Model 3 (Sections included: 2,3)**				**Model 4 (Sections included: 3)**			
Attribute	**Level**	**Utility**	**SD**	**[95%**	**CI]**	**Utility**	**SD**	**[95%**	**CI]**	**Utility**	**SD**	**[95%**	**CI]**	**Utility**	**SD**	**[95%**	**CI]**
Mobility	500m	50.2	26.0	47.1	53.2	69.2	27.4	66.0	72.4	39.7	27.8	36.4	42.9	55.8	28.7	52.5	59.2
	400m	17.7	20.0	15.4	20.1	25.9	17.8	23.8	28.0	21.0	21.2	18.5	23.5	25.4	16.2	23.5	27.3
	300m	5.6	15.3	3.8	7.4	0.9	14.2	-0.8	2.5	9.8	15.2	8.1	11.6	-0.3	12.4	-1.8	1.1
	200m	-14.1	15.7	-16.0	-12.3	-23.5	15.5	-25.3	-21.7	-10.1	18.8	-12.3	-7.9	-12.6	13.1	-14.1	-11.0
	100m	-21.3	16.4	-23.3	-19.4	-32.1	14.5	-33.8	-30.4	-21.3	18.8	-23.5	-19.1	-32.4	18.2	-34.6	-30.3
	50m	-38.0	18.9	-40.3	-35.8	-40.4	15.2	-42.2	-38.6	-39.2	21.6	-41.7	-36.6	-35.9	14.8	-37.7	-34.2
Risk of death	Low (3%)	77.8	27.8	74.5	81.0	60.5	18.4	58.3	62.6	81.5	28.5	78.2	84.9	83.8	20.3	81.5	86.2
	Medium (13%)	-8.6	22.1	-11.2	-6.0	1.6	15.2	-0.2	3.4	-11.0	20.4	-13.4	-8.6	-9.7	10.9	-11.0	-8.5
	High (23%)	-69.2	20.0	-71.6	-66.8	-62.1	12.7	-63.6	-60.6	-70.5	22.7	-73.2	-67.8	-74.1	15.6	-75.9	-72.3
Risk of hospitalization	Low (10%)	58.1	24.0	55.3	60.9	51.3	17.0	49.3	53.3	58.2	22.9	55.5	60.9	53.3	8.7	52.3	54.4
	Medium (25%)	-9.0	18.3	-11.2	-6.9	-8.1	19.9	-10.5	-5.8	-10.1	14.9	-11.9	-8.4	-27.7	10.7	-29.0	-26.4
	High (40%)	-49.0	15.2	-50.8	-47.3	-43.2	11.0	-44.5	-41.9	-48.1	18.8	-50.3	-45.9	-25.6	8.9	-26.7	-24.6
Type and frequency of monitoring	At home 9x per year	23.4	21.0	20.9	25.8	23.4	15.3	21.6	25.2	28.1	23.7	25.3	30.9	29.1	13.6	27.5	30.7
	At home 32x per year	0.4	19.0	-1.8	2.7	2.2	14.5	0.5	3.9	3.4	18.8	1.1	5.6	3.1	13.9	1.5	4.7
	At home 56x per year	-18.0	20.2	-20.4	-15.7	-28.2	17.2	-30.2	-26.2	-17.5	20.6	-19.9	-15.0	-34.4	13.8	-36.0	-32.8
	At the doctor 9x per year	40.2	20.2	37.8	42.6	51.8	14.8	50.1	53.6	31.4	20.1	29.1	33.8	34.6	14.4	32.9	36.3
	At the doctor 32x per year	-8.4	19.6	-10.7	-6.1	-12.4	17.1	-14.4	-10.3	-6.1	20.7	-8.6	-3.7	-9.8	10.3	-11.0	-8.6
	At the doctor 56x per year	-37.5	21.0	-40.0	-35.0	-36.9	17.3	-38.9	-34.9	-39.3	25.9	-42.3	-36.2	-22.6	15.3	-24.4	-20.8
Risk of medical device and system relevant complications	No risk (0%)	21.0	19.3	18.8	23.3	25.7	19.2	23.4	27.9	20.8	19.8	18.5	23.2	38.8	15.1	37.1	40.6
	Mild (1%)	4.8	15.0	3.1	6.6	6.3	19.1	4.0	8.5	3.2	13.7	1.5	4.8	-3.4	12.9	-4.9	-1.9
	High (2%)	-25.9	15.8	-27.7	-24.0	-31.9	14.9	-33.7	-30.2	-24.0	16.6	-25.9	-22.0	-35.4	15.4	-37.3	-33.6
	None	195.2	39.7	190.6	199.9	-	-	-	-	178.1	52.2	171.9	184.2	-	-	-	-
Number of respondents		*278*				*278*				*278*				*278*			
Parameters per respondent		*17*				*16*				*17*				*16*			
Pct. Cert.		*0.438*				*0.492*				*0.448*				*0.531*			
RLH		*0.637*				*0.533*				*0.666*				*0.626*			

Sections included in estimation: 1= BYO, 2= Screening, 3= Choice tasks; SD= standard deviation; CI= confidence interval

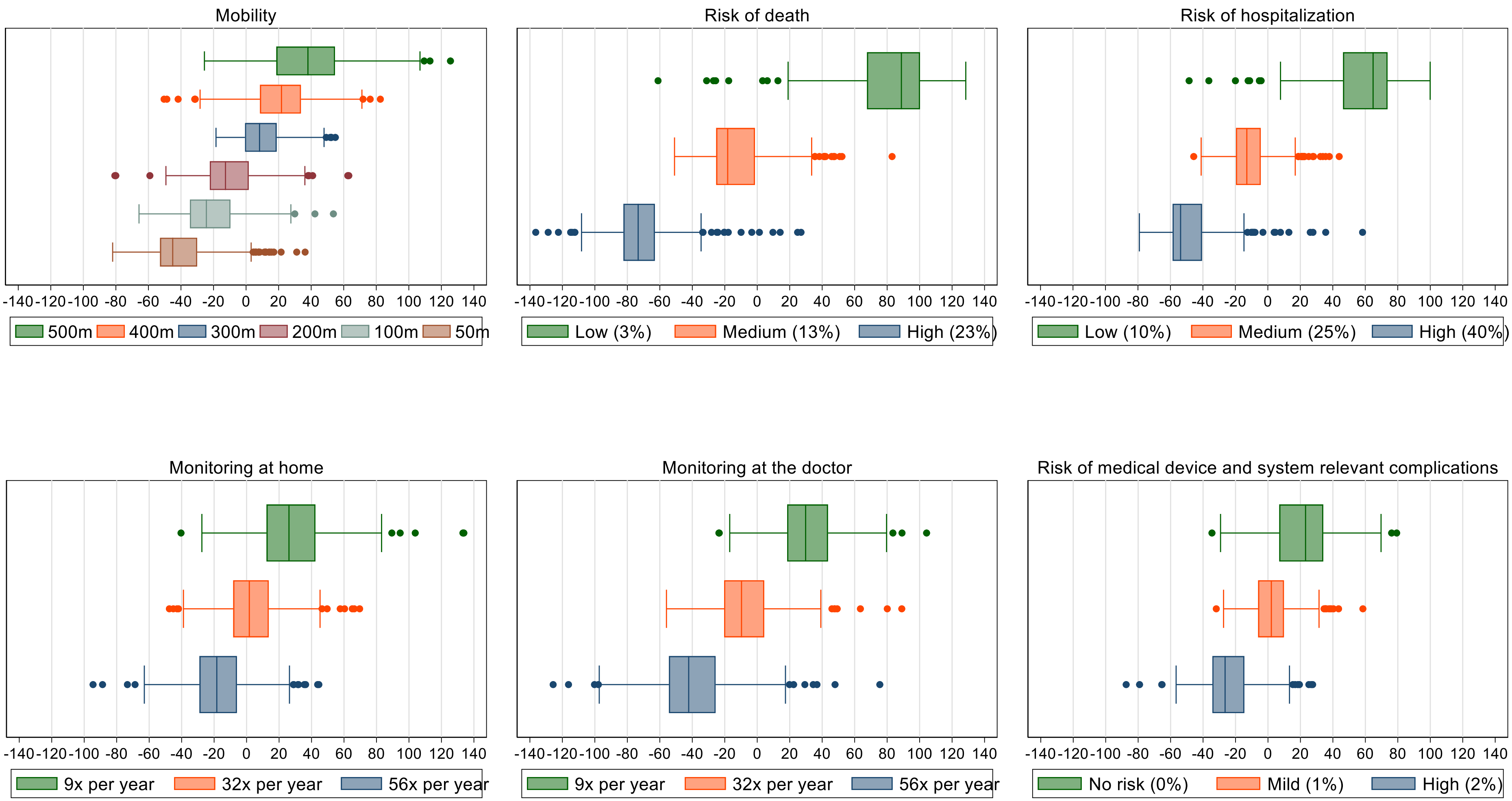

Figure 5. Boxplots of part-worth utilities for model 3

Figure 6 shows the utility curves of all levels in the diagram. The vertical lines around the mean value are the standard deviations. The levels of the attribute mobility show an approximately linear utility curve. The smaller the potential distance in meters, the smaller the benefit for the respondents. At about 250 meters, the utility value changes its sign. The steepest increase can be observed in the attribute risk of death. The change from one level to an adjacent level means a greater increase or loss of benefit. There is a similarly steep increase in the attribute risk of hospitalization. However, the last two levels seem to flatten out more than the last two levels of risk of death. The attribute type and frequency of monitoring was plotted in two separate curves. Here, too, there is an almost linear trend, although the curve for monitoring at home is somewhat flatter. For the attribute risk of medical device and system relevant complications, all part-worth utilities are close to zero indicating a low preference.

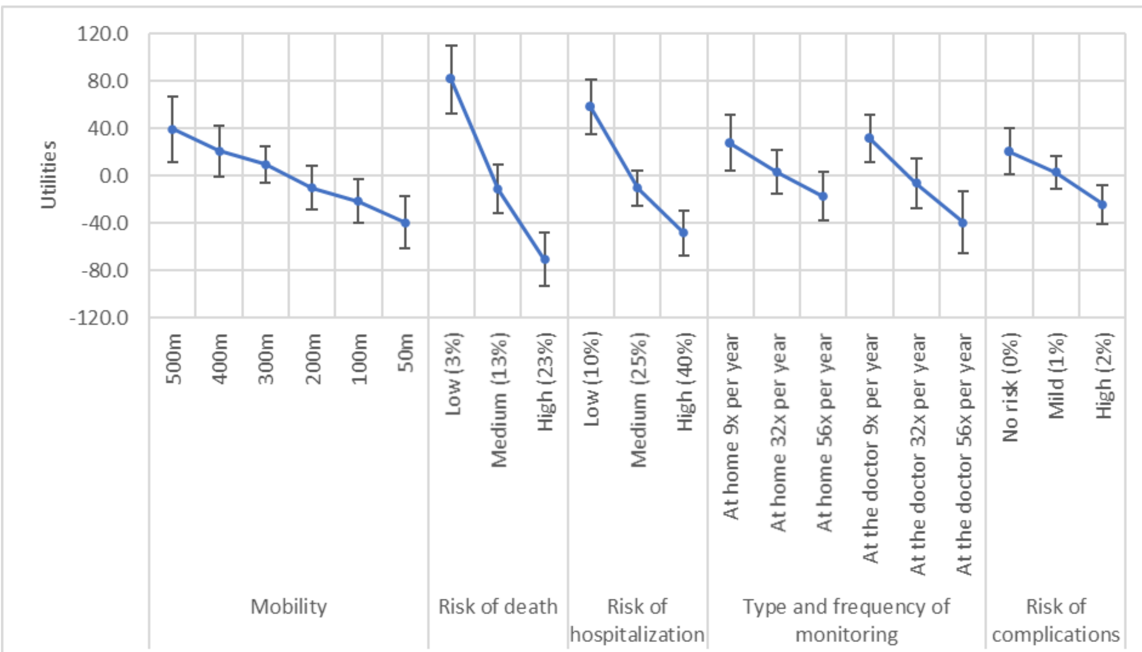

Figure 6. Part-worth utilities (zero-centered diffs) and standard deviations for model 3

Figure 7 shows the relative attribute importance of all attributes in comparison. The importance is calculated from the distance between the best and the worst level utility within an attribute, e.g., the distance between the utilities for 500m (79.7) and 50m (-39.2) mobility is 78.9. This difference is then related to the differences of the remaining attributes by normalization on a scale of 10. The most important attribute was risk of death, followed by risk of hospitalization, and mobility. This was followed by the attribute type and frequency of monitoring with monitoring at home being less important for respondents. The importance here refers to the change from the worst to the best attribute level in the model. In case of the attribute type and frequency of monitoring, this would mean that the switch from monitoring at the doctor 56 times to 9 times per year had a greater importance for the respondents than the switch from monitoring at home 56 times to 9 times per year.

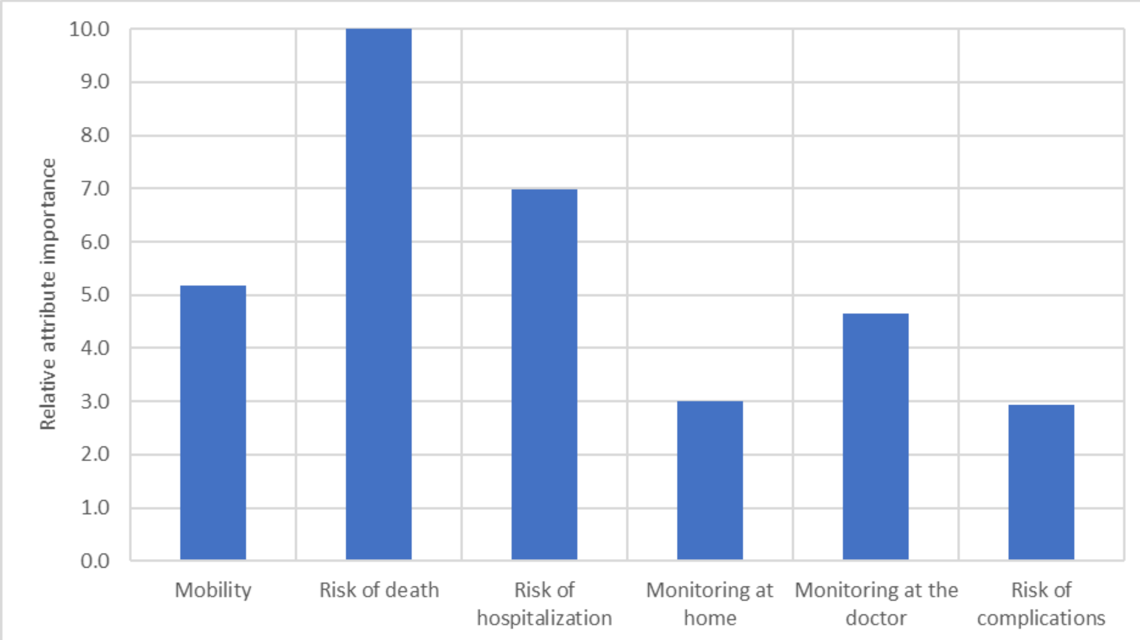

Figure 7. Relative attribute importance based on part-worth utilities for model 3

Discussion

CHF is a severe condition that places high demands on patient compliance and adherence. To better involve patients in the decision-making process of a therapy, which is also the preferred approach of respondents in this study, it is necessary to analyze patients' preferences and wishes. Decisions on the therapy of CHF are very complex and require a trade-off between possible outcomes such as improved mobility and at the same time more or less serious risks. The present study is intended to help analyze and better understand the preferences of heart failure patients.

The ACBC analysis confirms the results of previous study parts [2,3]. However, compared to other methods, the ACBC offers several advantages: The concepts presented are relevant for the respondent and the different sections make the survey more interesting for the participants. Accordingly, the respondents have the chance to exclude irrelevant attribute levels and include critical levels [8].

The BYO section is mainly used to specifically ask for the preferred level for attributes with unclear objective valence, to create the DCE based on this. In the study, this concerned the attribute type and frequency of monitoring. However, it remained unclear whether patients would prefer to be monitored more often or less often and where this monitoring should take place. The BYO section serves as the basis for the subsequent sections. Yet a misunderstanding on the part of an individual for the questions does not automatically lead to completely useless follow-up questions. The results of the following sections also confirm this, see for example the must have and unacceptable report from screener section. However, in the final Hierarchical Bayes estimation, the different models showed that the model with excluded BYO section performed best.

Given the advantages, the ACBC also shows some limitations. These include the fact that ACBC surveys take longer than a standard CBC survey which may result in additional costs [8,11]. Compared to standard CBC, which can be implemented and analyzed with various programs, researchers using ACBC require Sawtooth Software. And finally, surveys must be administered by computers, pencil and paper versions are not possible [9]. Moreover, the sample size of the study population (N = 278) is at the lower limits for this kind of study, which is a limitation.

Conclusion

The adaptive choice-based conjoint analysis (ACBA) shows that CHFpatients attached the highest importance to the risk of death. Second and third place were the risk of hospitalization and mobility. These results can be confirmed by a previously published RPL model based on a traditional DCE. Patients rated low risk of death and low risk of hospitalization higher than the other attribute levels in the decision context of this study. Higher risks of death and hospitalization would have a significant impact on patients' decisions to choose a treatment alternative. The type and frequency of monitoring was less important.

ACBA offers a practical approach to improving communication between patients and healthcare professionals on an individual level. Shared decision making can be enhanced since the knowledge of care providers concerning patient preferences is increased, the quality of interpretation of individual expected results can be improved and therapies can be made more patient-oriented based on the findings.

This will enable more effective and efficient patient care and increase patient benefits. In addition, it should be analyzed whether and under which circumstances the method of ACBA is too burdensome for CHF patients, e.g., older or less educated patients since this approach is cognitively more demanding.

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Conflict of interest
None.

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Appendix: Otter´s Method

In generic HB estimation all ACBC sections can be combined within the same dataset and parameters are estimated across the tasks, even though each section has different scale factor. A more sophisticated HB model separately models scale for the sections in the ACBC questionnaire. The so called “Otter’s Method“ accounts for differences in scale during HB estimation. About 300 respondents are recommended for stabile estimates of differential scale).

Table 6. “Otter's Method" for accounting for differences in scale during HB estimation

Attribute	**Level**	**Utility**	**SD**	**[95%**	**CI]**
Mobility	500m	50.2	26.0	47.1	53.2
	400m	17.7	20.0	15.4	20.1
	300m	5.6	15.3	3.8	7.4
	200m	-14.1	15.7	-16.0	-12.3
	100m	-21.3	16.4	-23.3	-19.4
	50m	-38.0	18.9	-40.3	-35.8
Risk of death	Low (3%)	77.8	27.8	74.5	81.0
	Medium (13%)	-8.6	22.1	-11.2	-6.0
	High (23%)	-69.2	20.0	-71.6	-66.8
Risk of hospitalization	Low (10%)	58.1	24.0	55.3	60.9
	Medium (25%)	-9.0	18.3	-11.2	-6.9
	High (40%)	-49.0	15.2	-50.8	-47.3
Type and frequency of monitoring	At home 9x per year	23.4	21.0	20.9	25.8
	At home 32x per year	0.4	19.0	-1.8	2.7
	At home 56x per year	-18.0	20.2	-20.4	-15.7
	At the doctor 9x per year	40.2	20.2	37.8	42.6
	At the doctor 32x per year	-8.4	19.6	-10.7	-6.1
	At the doctor 56x per year	-37.5	21.0	-40.0	-35.0
Risk of medical device and system relevant complications	No risk (0%)	21.0	19.3	18.8	23.3
	Mild (1%)	4.8	15.0	3.1	6.6
	High (2%)	-25.9	15.8	-27.7	-24.0
	None	195.2	39.7	190.6	199.9
Number of respondents		*278*			
Parameters per respondent		*17*			
Pct. Cert.		*0.443*			
RLH		*0.640*			

Sections included in estimation: 1= BYO, 2= Screening, 3= Choice tasks; SD= standard deviation; CI= confidence interval