Developing digital health interventions for falls prevention

An innovative user-centered design approach

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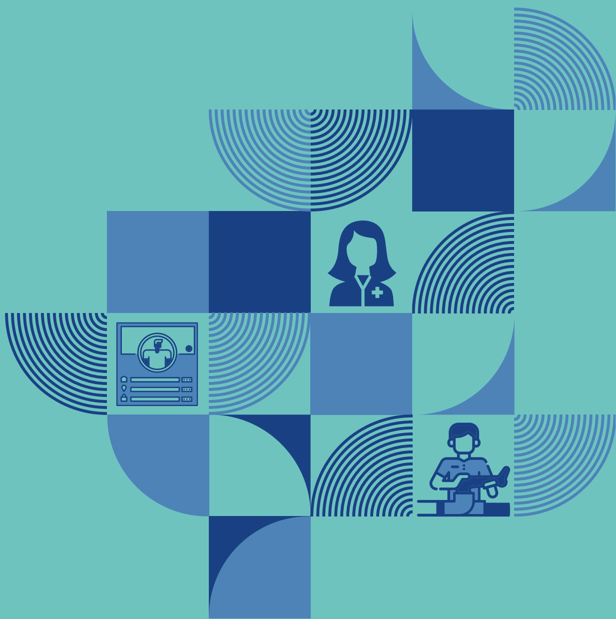
Chapter 2

Combining user-centered design and behavioral theory to enhance health technologies: A personas-based approach for a primary care-based multifactorial falls risk assessment tool



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Abstract

Introduction

Multifactorial falls risk assessment tools (FRATs) can be an effective falls prevention method for older adults, but are often underutilized by health care professionals (HCPs). This study aims to enhance the use and implementation of multifactorial FRATs by combining behavioral theory with the User-Centered Design (UCD) method of personas-construction. Specifically, the study aimed to (1) construct personas that are based on external (i.e., needs, preferences) and intrinsic user characteristics (i.e., behavioral determinants); and (2) use these insights to inform requirements for optimizing an existing Dutch multifactorial FRAT (i.e., the 'Valanalyse').

Methods

Survey data from HCPs (n = 31) was used to construct personas of the 'Valanalyse.' To examine differences between clusters on 68 clustering variables, a multivariate cluster analysis technique with non-parametric analyses and computational methods was used. The aggregated external and intrinsic user characteristics of personas were used to inform key design and implementation requirements for the 'Valanalyse,' respectively, whereby intrinsic user characteristics were matched with appropriate behavior change techniques to guide implementation.

Results

Significant differences between clusters were observed in 20 clustering variables (e.g., behavioral beliefs, situations for use). These variables were used to construct six personas representing users of each cluster. Together, the six personas helped operationalize four key design requirements (e.g., guide treatment-related decision making) and 14 implementation strategies (e.g., planning coping responses) for optimizing the 'Valanalyse' in Dutch geriatric, primary care settings.

Conclusion

The findings suggest that theory- and evidence-based personas that encompass both external and intrinsic user characteristics are a useful method for understanding how the use and implementation of multifactorial FRATs can be optimized with and for HCPs, providing important implications for developers and eHealth interventions with regards to encouraging technology adoption.

Introduction

Falls are among the leading causes of injury and accidental death in older adults (65+; WHO, 2021). Falls are a result of several risk factors, and improving modifiable factors is a recommended and effective falls prevention method when screened appropriately (Chang et al., 2004; Jehu et al., 2021; Montero-Odasso et al., 2022; Phelan et al., 2015). Evidence-based multifactorial falls risk assessment tools (FRATs) guide health care professionals (HCPs) in the (1) early risk stratification and assessment of modifiable risk factors in older adult fallers, and (2) selection of tailored interventions to effectively treat detected risk factors. Despite multifactorial FRAT implementation showing reduced falls and increased health quality in older adults in primary care, adoption remains low (Casey et al., 2016; Shubert et al., 2014; Vincenzo et al., 2021; White, 2020).

The development of multifactorial FRATs is primarily centered around ensuring the tool's clinical usefulness in a particular setting (McKay & Anderson, 2010). Multifactorial FRATs are therefore perceived as useful by HCPs for effective screening of older adult fallers in primary care (Casey et al., 2016). However, little attention is given to the tool's usability during development. Prior work highlights that multifactorial FRATs are perceived by HCPs as difficult to use, time consuming, and poorly integrated into workflows, suggesting that the usability of tools are not designed to fit the needs of users, resulting in low usage and consequently, adoption rates (Casey et al., 2016; McKay & Anderson, 2010; Shubert et al., 2014; Vincenzo et al., 2021). It is thus essential to explore how the use of multifactorial FRATs can be improved for users to encourage adoption and subsequently, realize the promising effects of such tools for falls risk management.

Research has suggested that adopting a User-Centered Design (UCD) approach to development could address the usability issues associated with multifactorial FRATs (Zhang et al., 2020). UCD is an iterative design process, whereby knowledge from users is sought throughout development starting from inception (Abras, Maloney-Krichmar, et al., 2005; Kujala, 2003; Norman & Draper, 1986). A method that is commonly used at inception is constructing personas. Personas are fictitious user descriptions that represent the 'at-large' needs of unique user groups. Personas facilitate user-focused thinking and decision-making in designers with research demonstrating the methods value in designing eHealth interventions (Bierbooms et al., 2021; Ledel Solem et al., 2020). Prior work has outlined two methodological approaches to personas-construction. The first approach is centered around aggregating distinct external user characteristics (e.g., needs, context, intuitive processes) to ensure the optimal usability of products (Abras et al., 2005; Albert & Tullis, 2023; Garrett, 2003; Goodman & Kuniavsky, 2012; Holden et al., 2017; Ledel Solem et al., 2020; LeRouge et al., 2013; Sandholdt et al., 2020; Witteman et al., 2015). The second, more novel approach is focused on eliciting intrinsic user characteristics using behavioral theory (Jansen et al., 2017) Specifically, in a case study involving users of a coaching app, Jansen et al. (2017) leveraged Self Determination Theory in personas-construction to identify for whom behavior was intrinsically regulated, and the unique determinants of change (i.e., intrinsic user characteristics) that drove this behavior, such as need for autonomy. Despite Jansen et al. (2017) providing valuable insight into the elicitation of intrinsic user characteristics in personas-construction, the authors did not examine how identified determinants of change can guide subsequent development, such as the use of theory-based methods aimed at changing behavior in interventions (i.e., implementation strategies; Bartholomew et al., 2011).

Personas research often includes either intrinsic or external user characteristics (Bierbooms et al., 2021; Holden et al., 2017; Jansen et al., 2017; Ledel Solem et al., 2020; LeRouge et al., 2013). However, personas that include both intrinsic and external user characteristics may more accurately reflect 'real-world' users. Given that both types of user characteristics have been shown to play an important role in health technology adoption, this results in missed opportunities for the development of health technologies (Garavand et al., 2016; Jacob et al., 2020). Health technologies that only cater to external user characteristics may not be as sufficient at encouraging adoption, as the development of these technologies solely focuses on improving the usability for users thereby neglecting potential behavioral determinants that facilitate adoption. On the other hand, if strategies for implementing the health technology only target intrinsic user characteristics, such as relevant behavioral determinants predicting adoption, than adoption may be hindered by the poor usability and consequently, use of the technology. As such, combining UCD and behavioral theory to construct personas that encompass both external and intrinsic user characteristics can be used to increase adoption by improving the use and implementation of health technologies. Thus, the aim of this paper is to (1) develop personas that are based on external and intrinsic user characteristics; and (2) use these personas to identify requirements for improving the use and implementation of a Dutch multifactorial FRAT.

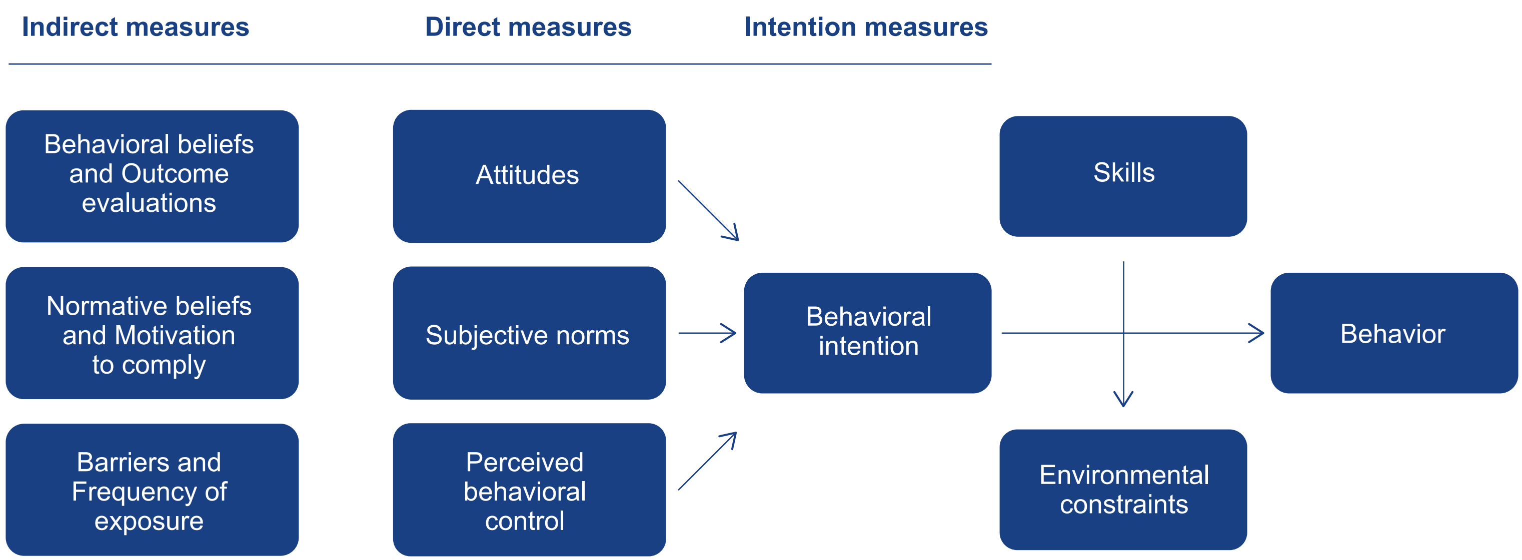
Materials and Methods

Choice of behavioral theory and multifactorial FRAT

To elicit the intrinsic user characteristics of users, we measured the behavioral determinants derived from the Integrated Model of Behavioral Prediction (IMBP) framework as shown in Fig. 1. The IMBP framework is a behavior change theory that posits that certain beliefs and barriers about a given behavior and related perceptions can positively or negatively influence an individual's intention to perform the given behavior, which is a strong predictor of actual behavior (Fishbein & Ajzen, 2011).

Developed by VeiligheidNL, the Dutch National Expert Center on Injury Prevention, the 'Valanalyse' makes use of validated questionnaires and functional assessments to aid primary care-based HCPs in screening for 13 (modifiable) risk factors for falls. The assessment is followed by selecting the appropriate preventive action (e.g., referral to a specialist) for each detected risk factor (VeiligheidNL, n.d.).

Fig 1. The behavioral determinants of the Integrated Model of Behavioral Prediction (IMBP) framework used as survey measures.



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Procedure

The research team recruited participants (N = 31) with the help of relevant stakeholders including GGD Amsterdam (i.e., the Public Health Department of Amsterdam), Elaa (i.e., a partner for healthcare and welfare in Amsterdam and Almere) and VeiligheidNL. A call for participants about the study with the survey link embedded was written by the research team. Sampling was done using a non-probability sampling approach. Specifically, the call for participants was distributed via email to a list of primary care-based HCPs in the Netherlands by the first author and via a news message leveraging the online communication channels of relevant stakeholders (e.g., monthly newsletter). A participant was included in the study if they were a HCP working in primary care in the Netherlands such as a physical therapist, general nurse practitioner, or district nurse; and current or past user of the 'Valanalyse.' Personalized reminder emails were sent to the list of primary care-based HCPs by the first author to increase the response rate after one month. Data was collected between July 2021 and October 2022 using the online survey software Qualtrics. The survey measured participants intrinsic (e.g., attitudes), external (e.g., situations for use), and background user characteristics (e.g., demographics; Fishbein & Ajzen, 2011; Witteman et al., 2015). The study was evaluated by the Medical Ethics Assessment Committee of the Amsterdam University Hospital (Amsterdam UMC, location AMC; W21_179 # 21.194) and declared that the Medical Research Involving Human Subjects Act does not apply to this study. Informed consent was obtained from all participants.

Survey measures

Table S1 in the supplemental materials displays the item wordings, answer scales, Cronbach's alphas, and descriptive statistics, where relevant.

Intrinsic user characteristics

Following IMBP, we compiled a list of salient beliefs, normative referents and barriers relating to falls risk management (Ajzen, 2006; Fishbein & Ajzen, 2011; Francis et al., 2004). For this, the first author reviewed both research reports from VeiligheidNL examining implementation barriers to falls risk screening in practice, and relevant falls prevention literature (Liddle et al., 2018; Mackenzie & McIntyre, 2019; Van Rhyn & Barwick, 2019). A total of four behavioral beliefs, two normative beliefs, and 11 implementation barriers were identified and used to construct the IMBP measures for the survey. Participants behavioral beliefs, outcome evaluations associated with each behavioral belief, normative beliefs, motivation to comply with each normative belief, and perceived barriers were measured using Likert-scales. Additionally, participants were asked to report how often each barrier actually occurred in practice (i.e., 1 = never to 4 = always). To compute the fraction of occurrence for each barrier, the four-point occurrence scale was recoded into a two-point occurrence scale (0 = barrier occurred sometimes and 1 = barrier occurred often; Brandes et al., 2015; Van Weert et al., 2009). Composite scores for the barriers were then calculated by multiplying the recoded fraction of occurrence of each barrier score with the perceived barrier score following the QUOTE (Quality of care through the patient's eyes) methodology described in Van Weert et al. (2009). For example, when a barrier occurred often according to 87,5% users and the mean perceived barrier score for that barrier was 6 on a seven-point scale, the QII score was labelled as 0.875 x 6 = 5.25. A QII score of .60 or greater indicated a potential barrier and a QII score of 1.75 or greater an influential barrier (Brandes et al., 2015; Van Weert et al., 2009).

Attitude was measured on a semantic differential scale using six items (Brandes et al., 2016). Three-items by Francis et al. (2004) measuring perceived norms toward implementation were adapted to fit the context of this study, and measured using a Likert-scale. For both attitude and perceived norms, internal consistency between items was assessed and, where necessary, items were removed to improve consistency. The remaining items were averaged where higher scores indicate more positive attitudes and perceived norms toward implementation, respectively. In turn, perceived behavioral control was assessed with one item using a semantic differential scale. Two-items were used to evaluate participants behavioral intention towards tool implementation using a Likert scale. Items were averaged, with higher scores indicating higher behavioral intention.

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External user characteristics

Context of use was assessed by examining situational and environmental cues to use. Intuitive process was assessed by evaluating whether participants encountered usability problems with the 'Valanalyse,' and how they intuitively solve these problems in practice (Witteman et al., 2021). Using multiple-choice items derived from research reports by VeiligheidNL, participants were presented with a list of eight situations for using the 'Valanalyse,' four usage environments for the 'Valanalyse,' eight usability problems with the 'Valanalyse,' and five solutions to use. Participants were provided with 12 identified needs for successful implementation of the 'Valanalyse' in practice and asked whether addressing each need would increase their likelihood of implementing the tool into practice on a Likert scale.

Background user characteristics

Participants were asked to indicate their age, sex, profession, number of years worked, an estimation of their older client base as a percentage, and an estimation of the consultation time per client. To assess prior experience with the 'Valanalyse,' participants were asked questions related to tool use (e.g., advice adherence).

Data analysis

Personas-construction

The statistical software IBM SPSS Statistics v.28.0.1 was used for data cleaning and analysis. Preceding data analysis, the data was cleaned and non-users of the 'Valanalyse' were excluded from the dataset (n = 30) yielding to a final dataset of n = 31. We then followed Holden et al. (2017) proposed steps for personas-construction by performing a Hierarchical Cluster Analysis (HCA), comparing identified clusters, and creating personas depicting users from the identified clusters. HCA is regarded as an effective clustering technique when clustering variables in high-dimensional low sample size data (Von Borries & Wang, 2009). Its validity has been demonstrated in sample sizes of ≤ 30 (Holden et al., 2017; Liu et al., 2008). The survey measures were used to perform the HCA with Ward's method in which participants were grouped into six clusters based on similar user characteristics (Holden et al., 2017). Each cluster represented a distinct group of users of the 'Valanalyse' and a persona that was representative of the users in a given cluster was constructed. Differences between clusters on clustering variables were examined through non-parametric analyses including Kruskal-Wallis Analysis of Variance, Fisher's Exact Test and Welch's Analysis of Variance (Holden et al., 2017). Non-parametric analyses are suggested for overcoming issues with small sample sizes (Tomarken & Serlin, 1986). An input variable qualified for personas-construction when it yielded a statistically significant difference, and the cluster value was then determined using different methods of computation (Holden et al., 2017). For ordinal variables (e.g., beliefs), values were transformed into a z-score between < -0.40 or > 0.40. The pertaining z-score was then used to provide a saliency label for each cluster ranging from 'Most', 'More', 'Less', or 'Least' salient. For example, when a belief z-score for a given cluster was the highest (i.e., z-score > 0.40) or the lowest (i.e., z-score < -0.40) compared to all other clusters, then that personas description received a label of 'Most likely to believe…' or 'Least likely to believe…', respectively. A variable was omitted from the personas descriptions due to non-saliency when the z-score for a cluster was between -0.40 and 0.40. Cluster proportions were examined to determine the cluster label for nominal variables. For example, regarding situations for use, a cluster received a definite label when all users used or did not use the 'Valanalyse' in a situation (e.g., 'Part of routine care…'). Clusters received a label of 'Likely' or 'Not likely' when proportions were skewed towards one side, and a label of 'Possibly' when proportions were even. Cluster means were used to determine the cluster value for all interval variables (e.g. age; Holden et al., 2017). Lastly, barriers with a quality impact indices (QII) of 1.75 or higher were perceived as influential for the cluster and were incorporated in the personas description for that cluster (Van Weert et al., 2009).

Operationalizing design and implementation requirements

The personas external user characteristics were used to inform key design requirements for improving the usability of the 'Valanalyse' through the aggregation of user needs. In turn, the personas intrinsic user characteristics were matched with behavior change techniques using the taxonomy of behavior change methods to inform implementation strategies for the 'Valanalyse' (Bartholomew et al., 2011; Kok et al., 2016).

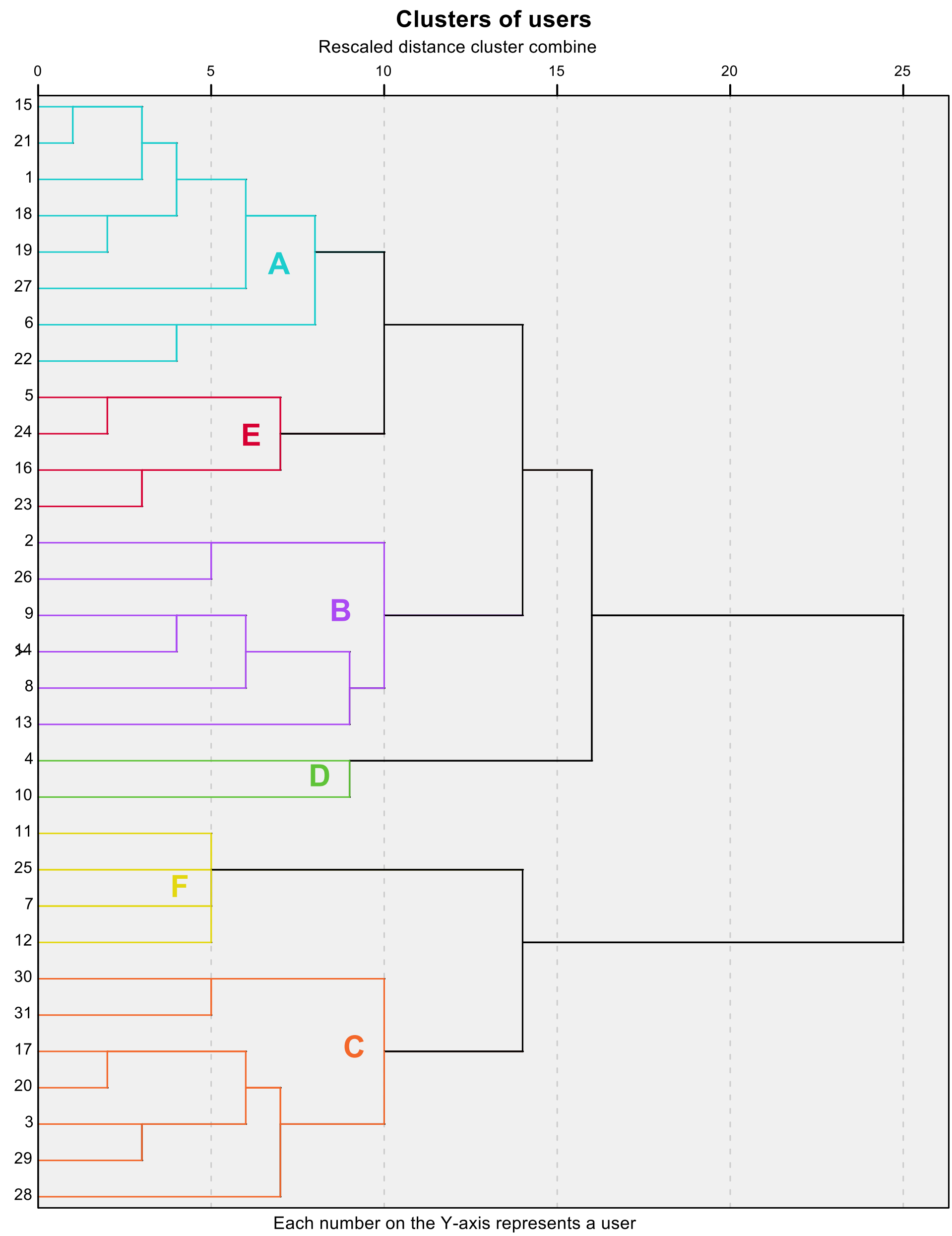
Results

The final dataset used for analysis (n = 31) comprised mostly of physical therapists (42%, n = 13) followed by occupational therapists (16%, n = 5), exercise therapists (16%, n = 5), and general nurse practitioners (13%, n = 4). The majority (87%) of participants were female, the mean age was 46.4 years old (SD = 13, range 41.6 – 51.2), and the mean number of years worked was 16.3 years (SD = 13, range 11.5 – 21.1). On average, participants reported having an older client base of 71% (SD = 22.8, range 20 – 100). The average consultation time per older client was 48 minutes (SD = 38.6, range 33.8 – 62).

Personas-construction

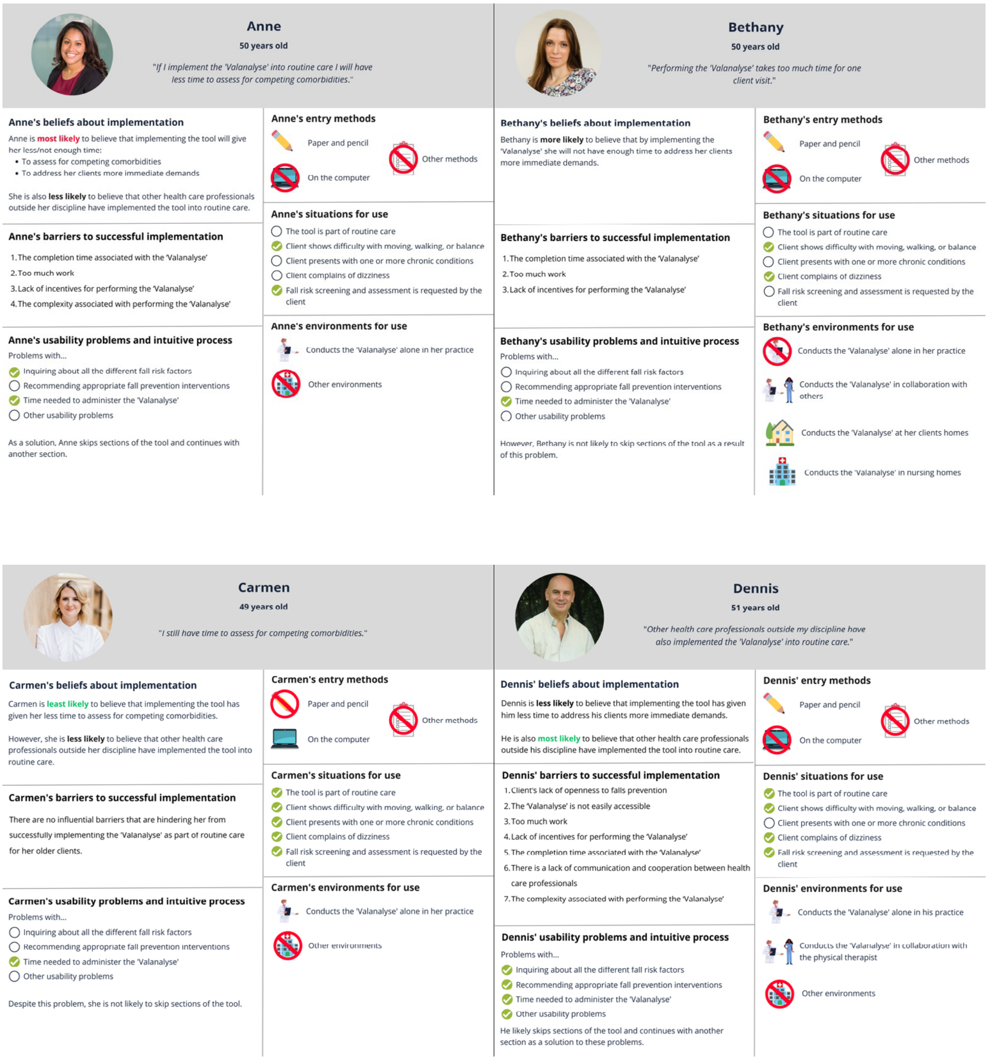
The HCA and Ward's method was performed to produce six distinct clusters as shown in the dendrogram in Fig. 2. Each cluster represented a distinct group of users of the 'Valanalyse' with clusters ranging between two and eight in size.

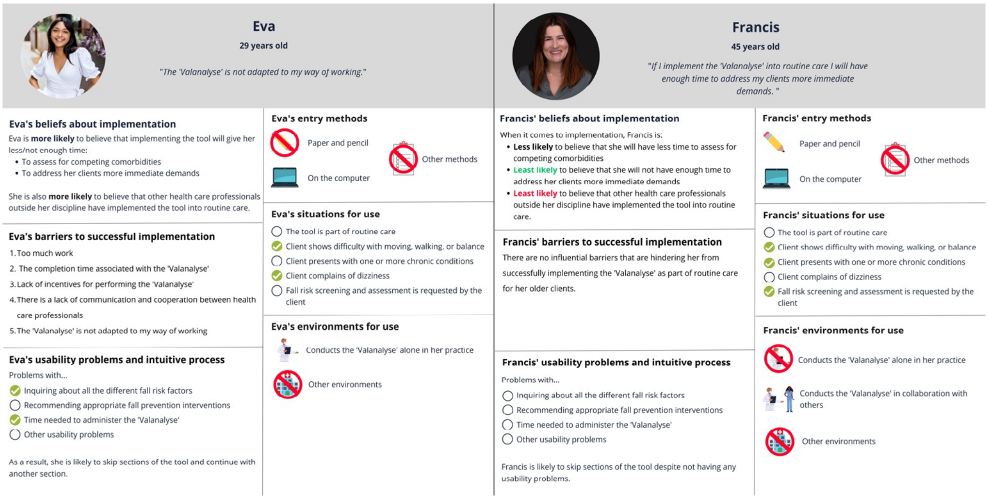
Fig 2. Dendrogram showing six distinct clusters.



Significant differences in characteristics between clusters were observed in 20 out of 68 variables (see Table S2 for test, p-values, cluster values and QII of barriers used to generate Table S3 in the supplemental materials). These characteristics were used to develop fictitious user descriptions representing six unique personas of the ‘Valanalyse’ that aimed to capture the ‘at-large’ needs of users in clusters one (n = 8), two (n = 6), three (n = 7), four (n = 2), five (n = 4) and six (n = 4). The final personas Anne, Bethany, Carmen, Dennis, Eva, and Francis are portrayed in Fig. 3.

Fig 3. Final personas Anne, Bethany, Carmen, Dennis, Eva, and Francis.





Key design requirements and implementation strategies

Regarding design requirements, the external user characteristics of the personas (e.g., environments for use) helped identify several areas for improvement which were aggregated into four key requirements (see Table 1). These requirements have been leveraged in the development of an online prototype for usability testing (i.e., the ‘Valanalyse 2.0’) which will serve as a first step toward improving the use of the multifactorial FRAT.

Table 1. Key design requirements for the 'Valanalyse.'

Design requirement	External characteristics	Design requirement description
1. Enhance assessment efficiency	Administration time too long (A, B, C, D, E)	The tool should enhance work efficiency by reducing completion time and the cognitive effort that users expend with regard to risk factor assessment.
	Problems with inquiring about risk factors (A, D, E)	
	Skips sections in the tool (A, D, E, F)	
2. Guide treatment-related decision making	Problems with recommending appropriate interventions (A, D, E)	The tool should guide users in the decision making process for the treatment of detected risk factors.
3. Provide different options for data entry	Paper and pencil (A, B, D)	The tool should be catered to different entry methods.
	On the computer (C, E)	
	Hybrid method (F)	
4. Improve adaptability across different usage contexts	Conducts the assessment in practice (A, C, D, E)	The tool should be useful in different contexts of use whereby the assessment of risk factors is easily carried out both in and outside of the usual practice setting following a single care or multidisciplinary care approach.
	Conducts the assessment at clients homes (B)	
	Conducts the assessment in nursing homes (B)	
	Collaborates with other professionals (B, D, F)	

Note. A = Anne, B = Bethany, C = Carmen, D = Dennis, E = Eva, and F = Francis.

The intrinsic user characteristics of the personas helped determine behavior change strategies for implementing the 'Valanalyse' into primary care and were guided by the taxonomy of behavior change methods (Bartholomew et al., 2011; Kok et al., 2016). This taxonomy provides a comprehensive overview of theory-based methods that are designed to change behavior in interventions by targeting one or more behavioral determinants (Bartholomew et al., 2011). A total of 14 behavior change techniques were classified and translated into implementation strategies that fit the context of this study (see Table 2).

Table 2. Implementation strategies for the 'Valanalyse' (Bartholomew et al., 2011; Kok et al., 2016).

Intrinsic characteristic	Behavior change technique (BCT)	BCT translated into implementation strategies	Intended effect
Behavioral beliefs (A, B, E)	1. Central arguments	Information encouraging tool use should be presented as arguments that are new to users.	Changes negative behavioral beliefs by eliciting central route processing of information
	2. Elaboration	The tool and related information should be perceived as personally relevant by users.	Changes negative behavioral beliefs by eliciting deeper elaboration of information
	3. Repeated exposure	The tool and related information should be made repeatedly available to users.	Changes negative behavioral beliefs by augmenting sensory receptors
	4. Cultural similarity	Common characteristics of users should be leveraged in tool-related messaging.	Changes negative behavioral beliefs by enhancing message receptivity
	5. Direct experience	Users should be assured that they can cope with and reframe from negative outcomes experienced in practice.	Changes negative behavioral beliefs by translating experience into knowledge (i.e., learning by doing)
Normative beliefs (A, F)	1. Mobilizing social networks	Help users build new or strengthen existing network linkages with different disciplines.	Changes normative beliefs by enhancing informational, emotional appraisal and instrumental support

Influential barriers (A, B, D, E)	1. Guided practice	Users should be prompted to repeat, rehearse, and reflect on experiences.	Helps overcome influential barriers by translating experience into knowledge (i.e., learning by doing)
	2. Enactive mastery	Users should be provided with patient cases that are increasingly more challenging.	Helps overcome influential barriers by serving as an indicator of capability
	3. Verbal persuasion	Users should be convinced of their capabilities for performing the desired behavior.	Helps overcome influential barriers by increasing credibility
	4. Self-monitoring behavior	Users should be encouraged to keep track of specified behavior(s).	Helps overcome influential barriers through positive reinforcement
	5. Goal setting	Users should be encouraged to define, plan, and commit to specified goals leading to the desired behavior.	Helps overcome influential barriers by enhancing commitment
	6. Provide contingent rewards	Users should be given tailored rewards for performing the desired behavior.	Helps overcome influential barriers through positive reinforcement
	7. Set graded tasks	Users should be provided with patient cases that vary in level of difficulty.	Helps overcome influential barriers by scaling down the behavior into sub-behaviors
	8. Planning coping responses	Users should be encouraged to come up with own solutions to identified barriers.	Helps overcome influential barriers by prompting strategies for coping

Note. A = Anne, B = Bethany, C = Carmen, D = Dennis, E = Eva, and F = Francis.

Discussion

This study demonstrated how combining UCD and behavioral theory can optimize personas-construction and subsequent health technology development in a geriatric, primary care context. We successfully constructed six personas of a Dutch multifactorial FRAT (i.e., the 'Valanalyse') using a quantitative approach and centered data collection around eliciting both external (i.e., UCD measures) and intrinsic (i.e., IMBP measures) characteristics of HCPs. Additionally, we showcased how external (e.g., intuitive processes, contexts of use) and intrinsic (e.g., behavioral beliefs) nuances across personas helped identify a total of four key design requirements and 14 behavior change techniques for enhancing the use and implementation of the 'Valanalyse,' respectively.

There is a clear need for developers of multifactorial FRATs to look beyond the tool's clinical usefulness and start exploring how the tool's usability can be maximized for users by incorporating UCD methods, such as personas-construction (McKay & Anderson, 2010). By constructing personas of the 'Valanalyse,' we were able to identify several requirements for optimizing the use of multifactorial FRATs as a whole and the 'Valanalyse' specifically. Previous research has identified time as an important facilitating factor for adopting multifactorial FRATs (Casey et al., 2016; McKay & Anderson, 2010; Shubert et al., 2014; Vincenzo et al., 2021). In line with previous research, the need to enhance assessment efficiency was found across all six of our 'Valanalyse' personas. This result has important practical implications for the development of multifactorial FRATs highlighting how developers of these tools should prioritize the incorporation of time-saving functionalities during development, as well as evaluate the added value of these functionalities in practice. More importantly, our personas helped identify user needs that were specific to the 'Valanalyse.' Interestingly, we found that the environment for use (e.g., alone in practice, multidisciplinary) and entry method (e.g., paper and pencil, computer) varied greatly between and within personas. For example, Francis (Persona F) uses the 'Valanalyse' in a multidisciplinary environment only, whereas Bert (Persona B) uses the 'Valanalyse' in three different environments, alternating entry methods within each environment. For developers and researchers, such variations between and within personas of a particular health technology can be useful for determining the subsequent step in the development process, such as making improvements to the user experience to further encourage technology adoption (Partala & Saari, 2015). In the context of this study, we conducted a follow-up study with users to gain insight into the different contexts of use, and how the tool's adaptability within these contexts can be optimized in order to improve the user experience of the 'Valanalyse' for users.

Although past research has demonstrated how intrinsic user characteristics can be elicited in personas through behavioral theory by applying qualitative methods, this study is novel as it demonstrated how such user characteristics can be elicited alongside key external ones through behavioral theory by applying quantitative methods (Jansen et al., 2017). We found that certain beliefs and barriers held by personas are hindering the successful implementation of the 'Valanalyse' into practice, which are also reflected across the literature (Ackerman et al., 2020; Barmentloo et al., 2020; McConville & Hooven, 2021). However, the strength of these beliefs and barriers fluctuated greatly between personas, suggesting that the position along the behavior change continuum varies between users, providing important implications for eHealth interventions. First, such insights into intrinsic user characteristics can give a clear understanding as to why different types of users are or are not performing the desired behavior, which is a key requirement for successful behavior change (Kok et al., 2016). Second, such insights can be used to inform behavior change strategies that effectively target identified determinants that aim to keep or advance a user's position along the behavior change continuum. In this study, we matched the identified intrinsic user characteristics of personas with behavior change techniques using the taxonomy of behavior change methods and translated these techniques into implementation strategies that could be integrated into a training module for the 'Valanalyse' (Bartholomew et al., 2011; Kok et al., 2016). For example, a behavioral belief held by HCPs, such as having less time to assess for competing comorbidities, could be effectively changed by acknowledging the negative belief (i.e., cultural similarity) and by assuring users that they can cope with and reframe from said belief in practice (i.e., direct experience; Bartholomew et al., 2011; Kok et al., 2016).

Strengths and limitations

A strength of this study is the elicitation of both external and intrinsic user characteristics in personas to inform requirements for improving the use and implementation of multifactorial FRATs in general and the ‘Valanalyse’ specifically. A limitation is that the majority of user data used for personas-construction came from physical therapists and users of the ‘Valanalyse.’ While interesting as the findings suggest how, even within a profession, users may differ with regards to their needs and behavioral determinants, more research is needed to determine whether this holds true for other professional groups as well. Moreover, a fruitful area for future research is to replicate this study among non-users to examine which requirements may enhance the use and implementation of multifactorial FRATs among this cohort.

Another strength of this study is the use of quantitative methods for personas-construction. This allowed for a systematic personas-construction approach, such as identifying distinct groups of users through clustering followed by examining differences between personas post clustering. As a result, we were able to detect important differences in tool use between users that helped inform requirements for the design of the optimized tool. However, a limitation of employing a quantitative approach to personas-construction, is that our personas could not provide insight into how these requirements can be operationalized in the tool, such as how to enhance the tool’s adaptability across different usage contexts for an improved user experience. Future research may benefit from a mixed-methods approach to personas-construction including both quantitative and qualitative methods.

Conclusion

This paper showcased how combining UCD and behavioral theory can optimize personas-construction and subsequent health technology development using a geriatric, primary care context. Based on important external and intrinsic user characteristics six personas were developed for maximizing the use and implementation of a multifactorial FRAT. Enhancing assessment efficiency and improving the adaptability of tools to different usage contexts were identified as important external user characteristics for using multifactorial FRATs in practice. In turn, intrinsic user characteristics, such as negative beliefs towards multifactorial FRATs and barriers, should be targeted with appropriate behavior change techniques and used for the implementation of multifactorial FRATs. As illustrated here, eliciting external and intrinsic user characteristics in personas-construction is highly useful for developers of eHealth interventions. Such personas can be used by developers to increase the likelihood of adoption of health technologies, as they provide simultaneous insight into the usability- and behavior change-related requirements for different types of users.

Acknowledgement

We thank GGD Amsterdam, Elaa, ROH Amsterdam and VeiligheidNL for assisting with participant recruitment.

Supplemental materials

Table S1. Item wordings, Cronbach's alphas, and descriptive statistics for survey measures (where applicable).

Measures	α	M	SD	N
BEHAVIORAL BELIEFS (*strongly disagree* to *strongly agree*):				
If I implement the 'Valanalyse' into routine care I will…				
Have to see my clients more often	-	4.34	1.74	56
Have less time to assess for competing comorbidities	-	4.45	2.00	56
Not enough time to address my clients more immediate demands	-	4.41	2.02	56
Doing something positive for my client's quality of life	-	5.48	1.56	56
OUTCOME EVALUATIONS (*extremely undesirable* to *extremely desirable*):				
Having to see my clients more often would be (un)desirable	-	4.29	1.55	56
Having less time to assess for competing comorbidities would be (un)desirable	-	2.11	1.19	56
Not having enough time to address my clients more immediate demands would be (un)desirable	-	2.30	1.49	56
Feeling that I'm doing something positive for my client's quality of life is (un)desirable	-	6.16	1.11	56
NORMATIVE BELIEFS (*definitely do not* to *definitely do*):				
Other healthcare professionals in my discipline implement the 'Valanalyse' into routine care	-	3.21	1.45	56
Other health care professionals outside my discipline implement the 'Valanalyse' into routine care	-	3.36	1.59	56

MOTIVATION TO COMPLY (*not at all* to *extremely*):				
Doing what other healthcare professionals do in my discipline is important to me	-	4.54	1.55	56
Doing what other healthcare professionals do outside my discipline is important to me	-	3.75	1.74	56
BARRIERS TO BEHAVIORAL CONTROL (*strongly disagree* to *strongly agree*):				
Lack of knowledge or skills	-	3.50	1.87	54
Too much work	-	4.75	1.97	55
Lack of incentives for performing the ‘Valanalyse’	-	4.75	1.98	53
There is a lack of communication and cooperation between health care professionals	-	4.53	1.81	55
Clients’ lack of openness to fall prevention (e.g., no recognition of the importance of fall prevention, don’t want to talk about their history of falls, etc.)	-	4.09	1.56	54
There is a lack of motivation from clients to make changes that would reduce their fall risk	-	4.13	1.72	55
My clients do not like to be referred to other health care professionals	-	3.83	1.60	53
The complexity associated with performing the ‘Valanalyse’	-	3.64	1.84	53
The ‘Valanalyse’ is not easily accessible	-	3.02	1.85	54
The ‘Valanalyse’ is not adapted to my way of working	-	3.38	1.83	53
The completion time associated with the ‘Valanalyse’	-	4.80	1.96	54

FREQUENCY OF OCCURRENCE OF BARRIERS (*never* to *always*):				
Lack of knowledge or skills	-	1.56	0.78	52
Too much work	-	2.38	0.84	53
Lack of incentives for performing the ‘Valanalyse’	-	2.12	1.05	51
There is a lack of communication and cooperation between health care professionals	-	1.79	0.72	53
Clients’ lack of openness to fall prevention (e.g., no recognition of the importance of fall prevention, don’t want to talk about their history of falls, etc.)	-	2.15	0.70	52
There is a lack of motivation from clients to make changes that would reduce their fall risk	-	2.08	0.70	53
My clients do not like to be referred to other health care professionals	-	1.73	0.64	51
The complexity associated with performing the ‘Valanalyse’	-	1.92	0.86	52
The ‘Valanalyse’ is not easily accessible	-	1.58	0.72	52
The ‘Valanalyse’ is not adapted to my way of working	-	1.75	0.82	51
The completion time associated with the ‘Valanalyse’	-	2.52	0.92	52
ATTITUDES:	.81	5.04	1.31	53
Inefficient - Efficient				
Not helpful - Helpful				
Not useful - Useful				
Impractical - Practical				
Not stressful - Stressful (reverse coded)*				
Disadvantage - Advantage*				

PERCEIVED NORMS (*strongly disagree* to *strongly agree*):	.93	2.62	1.60	53
I feel under pressure to implement the 'Valanalyse' into my routine care*				
My colleagues whose opinions I value expect me to implement the 'Valanalyse' into my routine care				
It is expected of me that I implement the 'Valanalyse' into my routine care				
PERCEIVED BEHAVIORAL CONTROL (*no control* to *complete control*):				
How much control do you believe you have over implementing the 'Valanalyse' into routine care?	-	5.34	1.37	53
BEHAVIORAL INTENTION (*strongly disagree* to *strongly agree*):	-	4.83	1.41	53
I plan to implement the 'Valanalyse' into my routine care				
I will try to implement the 'Valanalyse' into my routine care				
IMPLEMENTATION-RELATED NEEDS (*less likely* to *more likely*):				
I am rewarded for 'Valanalyse' related outcomes (e.g., certificates of achievements, performance measure)	-	4.75	1.63	53
I have regular access to training materials and practice guides related to the assessment of fall risk factors (e.g., fictional patient vignettes, instructional videos)	-	4.92	1.57	53
I have regular access to training materials and practice guides related to doctor-patient communication (e.g., strategies for reducing patient denial)	-	4.96	1.52	53
The 'Valanalyse' is linked to a more familiar and routinely addressed care outcome (e.g., frailty screening)	-	5.53	1.48	53

I receive reminders during the consulations with my clients to perform the ‘Valanalyse’ (e.g., pop-up)	-	4.09	1.96	53
The clients and/or caregivers fill in some questionnaires in the ‘Valanalyse’ together at home in advance of the consultation	-	4.92	1.52	53
I have the opportunity to collaborate with other healthcare professionals (e.g., support platform for sharing experiences, joint completion of the ‘Valanalyse’)	-	5.00	1.48	53
The ‘Valanalyse’ is adapted to my workflow	-	5.15	1.38	53
The ‘Valanalyse’ has a different layout	-	4.26	1.29	53
The ‘Valanalyse’ is digitalized (e.g., mobile phone application, webpage)	-	5.32	1.76	53
The ‘Valanalyse’ suggests patient-tailored advice or referrals after the assessment of fall risk factors	-	5.38	1.36	53
The ‘Valanalyse’ takes less time to complete	-	5.74	1.38	53
USER CHARACTERISTICS (*never* to *always*):				
How often in the past year have you followed the recommended advice based on the results of the ‘Valanalyse’?	-	2.83	0.74	36

*Items removed for improved internal consistency (α > .80)

Table S2. Results of cluster comparisons on clustering variables and the QII of barriers.

Characteristics	Test	Test value	*p*-value	Cluster value	Cluster 1 (N = 8)	Cluster 2 (N = 6)	Cluster 3 (N = 7)	Cluster 4 (N = 2)	Cluster 5 (N = 4)	Cluster 6 (N = 4)
INTRINSIC CHARACTERISTICS										
BEHAVIORAL BELIEFS										
Have to see my clients more often	KW	3.04	.694	-	-	-	-	-	-	-
Have less time to assess for competing comorbidities	**KW**	**19.73**	**< .05***	**z-score**	**1.04**	**0.04**	**-0.91**	**0.04**	**0.66**	**-0.58**
Not enough time to address my clients more immediate de-mands	**KW**	**15.28**	**< .05***	**z-score**	**1.03**	**0.44**	**-0.44**	**-0.47**	**0.53**	**-1.60**
Doing something positive for my client's quality of life	KW	7.12	.212	-	-	-	-	-	-	-
OUTCOME EVALUATIONS										
Desirability to see my clients more often	KW	1.27	.938	-	-	-	-	-	-	-
Desirability to have less time to assess for competing comorbidities	KW	8.37	.137	-	-	-	-	-	-	-

Desirability to not have enough time to address my clients more immediate demands	KW	7.15	.210	-	-	-	-	-	-	-
Desirability to feel that I'm doing something positive for my client's quality of life	KW	8.27	.142	-	-	-	-	-	-	-
NORMATIVE BELIEFS										
Other healthcare professionals in my discipline implement the 'Valanalyse' into routine care	KW	7.83	.166	-	-	-	-	-	-	-
Other health care professionals outside my discipline implement the 'Valanalyse' into routine care	**KW**	**12.73**	**< .05***	**z-score**	**-0.54**	**0.09**	**0.40**	**1.66**	**0.72**	**-1.01**
MOTIVATION TO COMPLY										
Doing what other healthcare professionals do in my discipline is important to me	KW	7.68	.175	-	-	-	-	-	-	-
Doing what other healthcare professionals do outside my discipline is important to me	KW	9.13	.104	-	-	-	-	-	-	-

DIRECT MEASURES										
Attitudes	KW	9.40	.094	-	-	-	-	-	-	-
Perceived norms	KW	7.74	.171	-	-	-	-	-	-	-
Perceived behavioral control	KW	7.93	.160	-	-	-	-	-	-	-
Behavioral intention	KW	9.61	.087	-	-	-	-	-	-	-
BARRIERS										
Lack of knowledge or skills	QII	≥ 1.75	-		0	0.60	0	0	0	0
Too much work	QII	≥ 1.75	-		**5.25**	**4.00**	0	**2.50**	**6.50**	1.19
Lack of incentives for performing the ‘Valanalyse’	QII	≥ 1.75	-		**4.50**	**2.25**	1.55	**2.50**	**4.31**	0
There is a lack of communication and cooperation between health care professionals	QII	≥ 1.75	-		0.63	1.67	0	**1.75**	**3.00**	0
Clients’ lack of openness to falls prevention (e.g., no recognition of the importance of fall prevention, don’t want to talk about their history of falls, etc.)	QII	≥ 1.75	-		1.00	1.44	0	**3.00**	0.94	1.06

There is a lack of motivation from clients to make changes that would reduce their fall risk	QII	≥ 1.75	-		0.59	1.55	0	0	1.00	1.00
My clients do not like to be referred to other health care professionals	QII	≥ 1.75	-		0	0.80	0	0	0	0
The complexity associated with performing the 'Valanalyse'	QII	≥ 1.75	-		**2.31**	0.58	0	**1.75**	0.94	0
The 'Valanalyse' is not easily accessible	QII	≥ 1.75	-		0.39	0	0	**2.75**	0	0
The 'Valanalyse' is not adapted to my way of working	QII	≥ 1.75	-		0.39	0.80	0	0	**1.88**	0
The completion time associated with the 'Valanalyse'	QII	≥ 1.75	-		**5.80**	**6.33**	0.49	**2.00**	**4.75**	0.69
EXTERNAL CHARACTERISTICS										
SITUATIONS FOR USE										
The 'Valanalyse' is part of routine care (65+)	**FET**	**16.13**	**< .001***	**%**	**0**	**0**	**71.4**	**100**	**25**	**0**

Client presents with one or more (chronic) conditions	**FET**	**19.30**	**< .001***	**%**	**0**	**33.3**	**100**	**50**	**0**	**50**
Client complains of dizziness	**FET**	**10.54**	**< .05***	**%**	**12.5**	**50**	**85.7**	**100**	**50**	**25**
Fall risk screening and assessment is requested by client	**FET**	**10.26**	**< .05***	**%**	**87.5**	**33.3**	**85.7**	**100**	**25**	**100**
Fall risk screening and assessment is requested by caregiver	FET	6.00	.319	-	-	-	-	-	-	-
Client is referred by another health care professional	FET	5.39	.323	-	-	-	-	-	-	-
Other situations for use	FET	7.13	.062	-	-	-	-	-	-	-
ENVIRONMENTS FOR USE										
Conducting the 'Valanalyse' alone in practice	**FET**	**15.51**	**< .05***	**%**	**50**	**0**	**100**	**50**	**75**	**25**
Conducting the 'Valanalyse' alone at client's home	FET	7.27	.127	-	-	-	-	-	-	-
Conducting the 'Valanalyse' in collaboration with health care professionals	FET	5.11	.298	-	-	-	-	-	-	-

Conducting the ‘Valanalyse’ in collaboration with caregivers	FET	2.34	1.00	-	-	-	-	-	-	-
Other environments for use	**FET**	**9.23**	**< .05***	**%**	**0**	**50**	**0**	**50**	**0**	**0**
USABILITY PROBLEMS										
Problems with the ‘Valrisicotest’ to estimate whether the client needs the ‘Valanalyse’	FET	7.77	.065	-	-	-	-	-	-	-
Problems with inquiring about all the different fall risk factors	**FET**	**12.62**	**<.05***	**%**	**50**	**0**	**14.3**	**100**	**75**	**0**
Problems with applying the different functional tests in the ‘Valanalyse’ in practice	FET	6.44	.267	-	-	-	-	-	-	-
Problems with the layout of the different forms (e.g., advice form)	FET	4.66	.443	-	-	-	-	-	-	-
Problems with the time needed to administer the ‘Valanalyse’	**FET**	**14.42**	**<.05***	**%**	**100**	**83.3**	**57.1**	**50**	**100**	**0**
Other usability problems	**FET**	**15.56**	**<.05***	**%**	**0**	**33.3**	**0**	**50**	**0**	**75**
No usability problems with the ‘Valanalyse’	FET	5.11	.298	-	-	-	-	-	-	-

SOLUTIONS TO USE										
Stop using the 'Valanalyse' during the consultation and draw own conclusions	FET	7.95	.092	-	-	-	-	-	-	-
Skip a section of the 'Valanalyse' and continue with another section	**FET**	**14.08**	**<.05***	**%**	**100**	**16.7**	**42.9**	**100**	**75**	**75**
Use a different fall risk screening and assessment tool or method	FET	4.28	.530	-	-	-	-	-	-	-
Contact VeiligheidNL and ask for help	FET[1]	-	-	-	-	-	-	-	-	-
Ask colleagues for help	FET	5.45	.383	-	-	-	-	-	-	-
Other solutions to use	FET	8.75	.066	-	-	-	-	-	-	-

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IMPLEMENTATION-RELATED NEEDS										
Rewarded for 'Valanalyse' related outcomes (e.g., certificates of achievements, performance measure)	KW	10.45	.063	-	-	-	-	-	-	-
Regular access to training materials and practice guides related to the assessment of fall risk factors (e.g., fictional patient vignettes, instructional videos)	KW	7.50	.186	-	-	-	-	-	-	-
Regular access to training materials and practice guides related to doctor-patient communication (e.g., strategies for reducing patient denial)	KW	8.96	.111	-	-	-	-	-	-	-
The 'Valanalyse' is linked to a more familiar and routinely addressed care outcome (e.g., frailty screening)	KW	8.10	.151	-	-	-	-	-	-	-

Receive reminders during the consultations with clients to perform the ‘Valanalyse’ (e.g., pop-up)	KW	7.79	.168	-	-	-	-	-	-	-
The clients and/or caregivers fill in some questionnaires in the ‘Valanalyse’ together at home in advance of the consultation	KW	5.17	.395	-	-	-	-	-	-	-
Opportunity to collaborate with other healthcare professionals (e.g., support platform for sharing experiences, joint completion of the ‘Valanalyse’)	KW	7.22	.205	-	-	-	-	-	-	-
The ‘Valanalyse’ is adapted to workflow	KW	8.12	.150	-	-	-	-	-	-	-
The ‘Valanalyse’ has a different layout	KW	5.23	.388	-	-	-	-	-	-	-
The ‘Valanalyse’ is digitalized (e.g., mobile phone application, webpage)	KW	5.74	.332	-	-	-	-	-	-	-

The ‘Valanalyse’ suggests patient-tailored advice or referrals after the assessment of fall risk factors	KW	4.75	.448	-	-	-	-	-	-	-
The ‘Valanalyse’ takes less time to complete	KW	10.04	.074	-	-	-	-	-	-	-
OTHER CHARACTERISTICS										
Profession	FET	24.22	.411	-	-	-	-	-	-	-
Number of years worked	WX	3.85	.061	-	-	-	-	-	-	-
Percentage of older client base	WX	0.10	.988	-	-	-	-	-	-	-
Time per client consultation (in minutes)	WX	1.74	.243	-	-	-	-	-	-	-
Followed the recommended advice based on the results of the ‘Valanalyse’	KW	3.86	5.71	-	-	-	-	-	-	-
Use paper and pencil	**FET**	**12.56**	**< .05***	**%**	**75**	**66.7**	**28.6**	**100**	**0**	**0**
Use Electronic	**FET**	**10.45**	**< .05***	**%**	**37.5**	**16.7**	**71.4**	**0**	**100**	**75**

Other entry method	**FET**	**9.19**	**< .05***	**%**	**0**	**33.3**	**14.3**	**0**	**0**	**75**
Age (in years)	**WX**	**12.92**	**< .05***	**Mean**	**50**	**50.17**	**49.14**	**50.50**	**28.50**	**44.50**
Gender[2]	**FET**	**10.25**	**< .05***	**%**	**100**	**83.3**	**100**	**0**	**75**	**100**

Abbreviations: KW = Kruskal-Wallis Analysis of Variance, QII = Quality Impact Indices, FET = Fisher's Exact Test, WX = Welch's Analysis of Variance; *Statistically significant difference observed between clusters; [1]Variable was a constant; [2]Dummy variable with female as reference category.

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Table S3. Distinct characteristics of the six personas

Characteristic	**Anne (N = 8 in C1)**	**Bethany (N = 6 in C2)**	**Carmen (N = 7 in C3)**	**Dennis (N = 2 in C4)**	**Eva (N = 4 in C5)**	**Francis (N = 4 in C6)**
Age	50	50	49	51	29	45
Sex	Female	Likely female	Female	Male	Likely female	Female
Have less time to assess for competing comorbidities	Most likely to believe		Least likely to believe		More likely to believe	Less likely to believe
Not enough time to address my clients more immediate demands	Most likely to believe	More likely to believe	Less likely to believe	Less likely to believe	More likely to believe	Least likely to believe
Other health care professionals outside my discipline implement the 'Valanalyse' into routine care	Less likely to believe			Most likely to believe	More likely to believe	Least likely to believe
Use of other entry methods	No other methods	Not likely other methods	Not likely other methods	No other methods	No other methods	Likely other methods

Use paper and pencil	Likely paper and pencil	Likely paper and pencil	Not likely paper and pencil	Paper and pencil	No paper and pencil	No paper and pencil
Electronic use	Not likely electronic	Not likely electronic	Likely electronic	Not electronic[a]	Electronic	Likely electronic
The ‘Valanalyse’ is part of routine care for older clients (65+)	Not part of routine care[a]	Not part of routine care[a]	Likely part of routine care	Part of routine care	Not likely part of routine care	Not part of routine care
When the client shows difficulties with moving, walking, or balance	Possibly when showing difficulties	When showing difficulties	When showing difficulties	Possibly when showing difficulties	Possibly when showing difficulties	When showing difficulties
When the client presents with one or more (chronic) conditions (comorbidity)	Not when comorbidities present	Not likely when comorbidities present	When comorbidities present	Possibly when comorbidities present	Not when comorbidities present	Possibly when comorbidities present
When the client complains of dizziness	Not likely when dizzy	Possibly when dizzy	Likely when dizzy	When dizzy	Possibly when dizzy	Not likely when dizzy

When a fall risk screening and assessment is requested by the client	Likely when requested by client	Not likely when requested by client	Likely when requested by client	When requested by client	Not likely when requested by client	When requested by client
Conducting the 'Valanalyse' alone in practice	Possibly alone	Not alone	Alone	Possibly alone	Likely alone	Not likely alone
Other environments for use	No other environments	Possibly other environments	No other environments	Possibly other environments	No other environments	No other environments
Problems with inquiring about all the different fall risk factors	Possibly problems with risk factors	No problems with risk factors	Likely no problems with risk factors	Problems with risk factors	Likely problems with risk factors	No problems with risk factors
Problems with recommending appropriate fall prevention interventions	No problems with recommending interventions	Likely no problems with recommending interventions	No problems with recommending interventions	Problems with recommending interventions	No problems with recommending interventions	No problems with recommending interventions
Problems with the time needed to administer the 'Valanalyse'	Problems with administration time	Likely problems with administration time	Likely problems with administration time	Possibly problems with administration time	Problems with administration time	No problems with administration time
Other usability problems	No other problems	Likely no other problems	No other problems	Possibly other usability problems	No other problems	Likely no other problems

I skip a section of the ‘Valanalyse’ and continue with another section	Skips a section	Not likely to skip a section	Not likely to skip a section	Skips a section	Likely to skip a section	Likely to skip a section
Influential barriers	The completion time associated with the ‘Valanalyse’	The completion time associated with the ‘Valanalyse’		Client’s lack of openness to falls prevention	Too much work	
	Too much work	Too much work		The ‘Valanalyse’ is not easily accessible	The completion time associated with the ‘Valanalyse’	
	Lack of incentives for performing the ‘Valanalyse’	Lack of incentives for performing the ‘Valanalyse’		Too much work	Lack of incentives for performing the ‘Valanalyse’	
	The complexity associated with performing the ‘Valanalyse’			Lack of incentives for performing the ‘Valanalyse’	There is a lack of communication and cooperation between health care professionals	

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The completion time associated with the 'Valanalyse'	The 'Valanalyse' is not adapted to my way of working
There is a lack of communication and cooperation between health care professionals	
The complexity associated with performing the 'Valanalyse'	

An empty cell indicates the variable was not salient for that cluster (see Table S2).