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How does varying the number of personas affect user perceptions and behavior? Challenging the 'small personas' hypothesis!

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ABSTRACT

Studies in human-computer interaction recommend creating *fewer than ten* personas, based on stakeholders' limitations to cognitively process and use personas. However, no existing studies offer empirical support for having fewer rather than more personas. Investigating this matter, thirty-seven participants interacted with five and fifteen personas using an interactive persona system, choosing one persona to design for. Our study results from eye-tracking and survey data suggest that when using interactive persona systems, the number of personas can be increased from the conventionally suggested 'less than ten', without significant negative effects on user perceptions or task performance, and with the positive effects of increasing engagement with the personas, having a more diverse representation of the end-user population, as well as users accessing personas from more varied demographic groups for a design task. Using the interactive persona system, users adjusted their information processing style by spending less time on each persona when presented with fifteen personas, while still absorbing a similar amount of information than with five personas, implying that more efficient information processing strategies are applied with more personas. The results highlight the importance of designing interactive persona systems to support users' browsing of more personas.

1. Introduction

Personas are fictitious people (Cooper, 1999) that portray the needs, wants, and goals of distinct end-user groups – end-users that can represent customers, software consumers, patients, gamers, or any other community of interest (Anvari and Richards, 2016; Idoughi et al., 2012; Nielsen and Storgaard Hansen, 2014). Personas are considered useful in design processes (Hult et al., 2006; Zhou et al., 2020) that are defined as *activities of user-centric decision making in a range of contexts and job functions* (Antle, 2006; Cutting and Hedenborg, 2019; Dow et al., 2006; Helgason and Smyth, 2020; Houben et al., 2020; Kannabiran et al., 2020; Raijmakers et al., 2006; Rubegni et al., 2020; Theil et al., 2020; Zhu et al., 2019) *by software developers, designers, marketers, and other stakeholders* (Fuglerud et al., 2020) – collectively referred to as 'persona users' or 'users' for short. However, in contrast, we refer to end-users as the people who the personas represent.

Personas are widely applied in both research and industry practice (Adlin and Pruitt, 2010). Literature reviews of human-computer interaction (HCI) show that personas have been studied and deployed for more than a decade, with consistent and pervasive interest (Goh et al., 2017; Salminen et al., 2020b). Despite the substantial progress that has been made in persona research, there remain a myriad of issues to address. One of these issues is a fundamental yet unexplored question: *How many personas should one create?* The current body of knowledge on personas involves arguments for both "more" and "less" personas, although arguments currently lean towards the "less" side (see Section 2). The predominant counterargument or hesitation against creating more personas is that this may result in an adverse effect where designers and developers face a cognitive overload of all the shown end-user information that hinders, rather than helps, their decision making. Some data-driven methods, such as clustering, can also result in a handful of personas only when using conventional means for determining the number of clusters.

On the other hand, if the number of personas is too small, then

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designers and developers risk missing central end-user needs, misinterpreting their end-users, and overlooking marginalized end-user groups, which is concerned alarming from the objective of inclusive design (Goodman-Deane et al., 2018; (Goodman-Deane et al. 2021)), and also when considering the needs of marginalized end-users. For example, researchers have identified gender-specific issues in software (Burnett et al., 2016), implying the need for gender-inclusive design. As stated by Goodman-Deane et al. (2021), "Digital inclusion is becoming more important as many consumer products and engineered systems adopt increasingly digital interfaces" (p. 1203). In our case, the interface is the persona, and more personas afford coverage of more demographic and behavioral variations that can be beneficial for inclusive design.

The extant HCI literature provides a wide range of suggestions to the number question, with heuristic reasonings such as "a reasonable number" (Blomquist and Arvola, 2002) (p. 198), "a rule of thumb is" (Goodman et al., 2013) (p. 488), and "a manageable number" (Pruitt and Grudin, 2003) (p. 2). Most sources suggest that the optimal range is 'fewer than ten,' which is discussed further in our literature review. But despite this suggested range, no empirical evidence of a single "magical number" (or range) of personas being ideal exists, even though determining the number of personas is one of the most influential design choices in the persona creation process. As far as we know, no prior study empirically investigates how many personas are appropriate for a given end-user population, design project or work task, with the end result that the determination of the number of personas tends to rely on heuristic guidelines rather than validated knowledge (Canossa and Drachen, 2009; Marsden et al., 2015; Mulder and Yaar, 2006; Pruitt and Adlin, 2006). Currently, the primary indication from both literature and design practice is that 'no one knows for sure' what the number of personas *should* be, but the literature tends to presume it is probably a relatively small number.

In the absence of empirical evidence about the number of personas, *ad hoc* recommendations are implemented. However, these may undermine effective designs and lead designers astray. Importantly, designers may further be compelled to follow truisms that are not based on scientific evidence, which undermines the credibility of the persona creation effort as a whole. Considering that credibility is a key issue of personas among stakeholders (Matthews et al., 2012; Rönkkö et al., 2004), this situation is not desirable. Moreover, the large number of truisms and lack of empirically validated knowledge has been seen as a hindrance for progress in persona science (Salminen et al., 2021b). Therefore, previous work that bases its understanding on the number of personas in a heuristic tradition may propagate critical fallacies about the number of personas. These potential fallacies have largely gone unnoticed in research, but they can have an enduring negative effect on the application of personas across multiple domains in research and practice.

A critical observation here is that the 'fewer than ten' rule of thumb was proposed in the era when personas were primarily disseminated in a paper-like, flat file format that might favor fewer rather than more personas, and due to the limitations of the medium for disseminating personas to stakeholders, it seems unreasonable to print a large number of paper sheets and present them in stakeholder meetings. There are also other common challenges pertaining to persona creation, wherein the data collection modes have traditionally favored small samples (Nielsen, 2019) that consequently result in a small number of personas because there is relatively little variability (i.e., a small sample usually does not reflect the full range of the end-user population).

The theoretical belief that there should be fewer rather than more personas is based on the notion that there is always a trade-off between more personas and a higher cognitive cost for persona users. This presumed trade-off has caused many researchers to forgo the effort to generate more personas that would better represent the variability of the end-user population. This concern is intensified by the fact that researchers tend to be trained either in persona creation or interactive system design, but not in both of these areas at the same time. Also, existing tools for persona creation have traditionally provided little in the way of usable interfaces for coping with a large number of personas. In other words, the UI/UX aspects of persona *systems* lag behind the persona creation algorithms.

However, there have been a series of attempts to introduce *interactive persona systems* that can offer functionalities for users so that they may more easily cope with a larger number of personas compared to the traditional paper format. These functionalities include options to filter/navigate/sort and generate an arbitrary number of personas (Jung et al., 2018a,b). The interaction features provided by such systems can possibly alleviate the users' cognitive restrictions of facing "more than ten" personas, and can (at least in theory) offer stakeholders a large number of personas without posing a manageability issue of a cognitive overload of information (Salminen et al., 2020c; Spiliotopoulos et al., 2020). Moreover, these data-driven interactive persona systems can generate more personas to represent diverse traits, behaviors, and demographics in the end-user population, thereby addressing central shortcomings in traditional persona creation that is based on a manual interpretation of patterns in the source material (Kaasinen et al., 2015).

Given these novel opportunities for personas, testing the 'small personas hypothesis' (SPH) is a timely research endeavor, as it currently poses an impediment for the fundamental issue of representing diverse end-user populations for achieving inclusive design goals that cannot necessarily be accomplished via just a handful of personas. In contrast, if the SPH holds, we would expect to see adverse outcomes from the use of more personas in our experiment.

Therefore, '*Should there be fewer or more personas?*' is a topical and important question to address in HCI research. The timeliness of this issue is further exacerbated by the contemporary trends of data-driven persona development (Zhang et al., 2016) and interactive persona systems (Jung et al., 2018) that suggest that more personas may possibly be advantageous, especially when the goal is to represent large and heterogeneous online end-user populations. Given the impact of personas in HCI research and practice, two key questions remain unanswered in the current body of knowledge about personas: (a) *Are the rules of thumb for the number of personas valid?* (b) *What are the benefits and drawbacks of increasing or decreasing the number of personas?*

These questions motivate the current research, in which we conduct an in-person within-participant user study using two personas sets – one with *fewer than ten* personas and one with *more than ten* personas. In the study, participants complete a professional task in their work environment using an interactive persona system. We employ multiple data collection modes, including eye tracking, mouse tracking, a think-aloud protocol, and conduct a post-session survey to investigate the hypotheses derived from our research questions.

The remainder of the work is organized as follows. The following section summarizes the related research. This is followed by an introduction of research questions and hypotheses. We then explain our methodology, including data collection and analysis procedures. Subsequently, the results are presented and discussed, paying particular attention to the study's contributions to persona design theory and practical design implications. We conclude by outlining the main limitations of the research and pointing out avenues for future research.

2. Literature review

2.1. Suggested numbers

Although the most effective number of personas has not been empirically researched in any study that we are aware of, the common postulations presented in prior persona research state that the typical range is *five to ten personas* (Marsden et al., 2015). In industrial design projects the norm is *six or fewer*, with the observed personas rarely exceeding 12 (Nielsen et al., 2015; Viana and Robert, 2016). Authors typically justify these numbers of personas using phrases such as "a reasonable number" (Blomquist and Arvola, 2002) (p. 198) or "a

manageable number" (Pruitt and Grudin, 2003) (p. 2), implicitly assuming that a larger number would *not* be manageable and therefore not even considered.

While these heuristic numbers and rules are helpful to a degree, as they provide persona developers at least *some* guidance; they are typically given with little or no empirical justification, which makes their wider use precarious and susceptible to fallacious thinking. Moreover, the precise suggestions given in the literature do not always agree with each other, although they almost always recommend a small number of personas, i.e., 'less than ten'. From Table 1, one can see that most authors tend to recommend fewer than ten personas, but how it came to be 'fewer than ten' and whether 'fewer than ten' would be better than 'more than ten' is not clear.

The heuristic rules commonly appear in both research articles and authoritative persona textbooks, such as Mulder and Yaar (2006) recommending three to six personas, Pruitt and Adlin (2006) recommending three to five personas, and Cooper (2004) advocating for one primary persona and a number of secondary personas (although Cooper does mention that the possibility of having more personas can be beneficial for some projects).

2.2. Applied numbers

One of the few studies to mention more than ten personas is by Goodman et al. (2013) who advocate one persona for each organizational role, but this is provided with little to no empirical support. Canossa and Drachen (2009) suggest three to twelve personas for videogame design, while (An et al., 2018a; An et al., 2018b) use five to fifteen personas to describe a geographically and behaviorally diverse online news audience. Overall, Fig. 1 shows the frequency of the numbers of personas featured in the 358 studies we reviewed for this research, and more than 90% of the studies develop fewer than ten personas, with the average number of personas across all research studies as $\boldsymbol{M} = \mathbf{4.51}$ personas, and the mode even less at **MD=2** personas.

Table 1
Recommendations for the number of personas in the literature. The articles ($N =$ 358) were retrieved from Google Scholar by searching for 'n personas' [$n =$ number of personas, e.g., '2 personas/two personas'] and then assessing from the text of the articles whether or not the researchers developed the specific number of personas. References to the articles are provided in the online appendix.

Recommendation	Reference	N* (%)
fewer than 10	"…persona sets usually contain **less than ten personas"** (p. 393) (Marsden et al., 2017a).	329 (91.9%)
from 3 to 7	"In general, **three to seven personas** are developed …" (p. 2) (Hong et al., 2018)	220 (61.5%)
from 3 to 5	"The target is usually to develop a persona set of between **three and five personas**." (p. 394) (Marsden et al., 2017b).	183 (51.1%)
from 3 to 4	"The majority of persona literature results in the creation of **three or four personas**" (p. 544) (Brickey, 2010).	156 (43.6%)
from 4 to 10	"Persona sets use around **4–10 personas**" (p. 101) (Marsden et al., 2015) [translated from German]	162 (45.3%)
from 4 to 6	"The literature on personas recommends developing **four to six personas**" (p. 2) (Jensen et al., 2018)	125 (34.9%)
from 5 to 8	"As a rule of thumb, most systems are represented by only about **5–8 personas**." (p. 88) (Cleland-Huang, 2013)	74 (20.7%)

*N indicates the number of articles that develop personas corresponding to the range specified in the recommendation. The numbers overlap; for example, "3 to 7″ includes all "3 to 5″ papers.

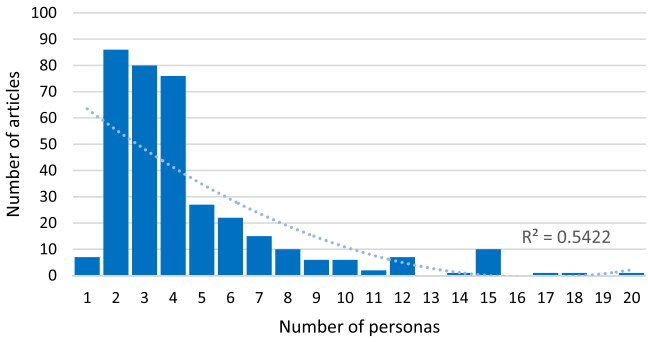


Fig. 1. The number of articles developing a specific number of personas based on 358 peer-reviewed articles that develop personas (see the list in the online appendix). There are relatively few articles that develop more than ten personas, apart from twelve and fifteen personas that show a visible decrease.

2.3. Given reasoning

To justify the choice for the number of personas, researchers tend to use somewhat vague and non-scientific expressions such as *emerging* ("Seven personas emerged during the workshop" (Sankupellay et al., 2015) (p. 414)) and *appearing* ("From the analysis, a cast of five personas appeared" (Nielsen, 2013) (p. 131)). In another line of reasoning, personas were *identified* or *defined* from the data, but the exact process is not explained in a way that makes replication or any detailed scrutiny possible. The researchers' past personal experiences were also used to justify the choice: "We (…) developed two personas based on our knowledge in interacting with elderly …" (Al-Razgan et al., 2014) (p. 419). Overall, these reasonings suggest a considerable degree of subjectivity, which is somewhat alarming because the persona creators are not always the people using the personas.

Manageability of the persona set is fairly frequently mentioned as a rationale for choosing the number of personas; for example: "Three to seven personas is a manageable number, although there are no absolute limits" (Feldstein and Neal, 2006) ('Creating Your Personas', para. 3). A particular determinant is striking a balance between manageability and "what the data tells": "[more personas] should be extracted, but here we focus on generating two Components since that would yield four Personas (any more Personas being unwieldy)" (Greaney and Riordan, 2003) (p. 479). Their rationales suggest that some researchers are aware of the artificial nature of limiting the number of personas (i.e., going against the data), but they place greater importance on the (presumed) user-friendliness of personas and thus decide to limit the number. This is, again, a dangerous practice because it restricts the persona users' viewpoints on the full spectrum of end-user types, on the premise that persona users could not handle the real degree of diversity, and must instead be presented with an oversimplification of reality.

Other researchers present *data-driven* argumentation, such as "eight personas were systematically developed in a best-practice approach taking quantitative data into account, external data, and fictional elements." (Schäfer et al., 2019) (p. 5). More formal reasoning is applied in quantitatively-oriented persona creation, where "frequently visited library locations suggested end-user attributes for the development of five personas" (Kim and Wiggins, 2016) (p. 643). These reasonings tend to be based on finding the optimal number of components, patterns, or clusters, using short-hand techniques such as the elbow method or cumulative variance explained (Huang et al., 2019). Even though in these cases the reasoning might appear to be more precise and pronounced than in the case of qualitative personas, quantitative or data-driven personas also involve a degree of subjectivity when determining the number of personas, stemming from the fact that this choice deals with hyperparameter selection which is recognized as an art rather than a precise science (Jansen et al., 2021). Nonetheless, the methods used to generate these quantitative and data-driven personas are often

described in somewhat more detail and tend to be more reproducible than those used in qualitative personas (Goodman-Deane et al. 2021).

From the above reasonings, we can identify three main strategies that researchers apply to determine the number of personas: (1) *inductive reasoning*, where the number is a consequence of the analysis or reflects the opinions of the researcher; (2) *pragmatic reasoning*, where the number is based on striking a balance between the data-optimal number and the user-optimal number, and (3) *data-driven reasoning* that assigns the number based on statistical quantifiers, metrics, functions, or calculations. Also, we should note that many studies give no reasoning at all, and just describe how many personas were created without offering further explanation (e.g., "We provided three personas…" (Houben et al., 2020) (p. 45)). The fact that such reports passed the peer-review stage is not ideal, as the persona creation process should be reported rigorously to increase the stakeholders' trust in the validity of the created personas (Matthews et al., 2012) and make it possible to replicate the research.

3. Research gap

Persona research investigating the impact of the number of personas on stakeholder activities (i.e., perceptions and behaviors) is important because recommendations that start as suggestions tend to become adopted as the norm over time, even when not grounded on empirical or theoretical foundations. Thus, "in general, three to seven personas are developed" (Hong et al., 2018) (p. 2) becomes, in a later work from different researchers: "Each project should have between three and seven personas." (Johnson, 2008) (p. 157, emphasis added). As can be seen, the number is no longer "can be" or "is suggested" but "*should* be." Passages such as these show that practices are passed on in the research community, and may become entrenched or immutable over time (Rudin, 2019). This is dangerous when the norm is born without strong empirical support for different sizes of persona sets. As the literature review shows, the majority opinion within persona literature is to generate fewer rather than more than ten personas (which is a widely spread premise with no empirical evidence and little theoretical justification), and this low amount based on the idea that stakeholders cannot cope with a lot of information. Yet it is unclear whether this is true, or whether the idea is a myth that should be debunked.

A crucial element here is that there is no pre-existing study that we could locate investigating whether the number of personas should or could be higher for *interactive persona systems* (Jung et al., 2018a,b) than for personas using other forms of media (e.g., paper, slideshows). Here, we specifically employ an interactive persona system, and although we do not compare it against other media used for personas, our findings give direct evidence of how persona users make use of interactive features when browsing a larger-than-traditional number of personas. Therefore, the current research contributes to the persona design literature within HCI, with implications for researchers and practitioners employing personas, especially those served via interactive systems, in their user-centered design projects. Our findings benefit researchers and practitioners by informing them of the possible advantages and/or disadvantages of having fewer or more personas, and of building systems and user interfaces (UIs) that support the browsing of more personas.

4. Research questions and hypotheses

We formulate 13 hypotheses based on two alternative interpretations: (a) that it is better to show *fewer* personas to users (SPH), and (b) that it is better to show *more* personas to users (big personas hypothesis, i.e., BPH). Each interpretation is clarified in the following subsections.

4.1. Small personas hypothesis

Given that the existing persona literature leans towards *fewer* rather than *more* personas, we propose several hypotheses expecting that more personas *will have a detrimental effect*, which, again, is in line with most of the suggestions seen in the literature. We refer to this as the Small Personas Hypothesis or SPH. Central to this is the idea that more personas would be too cognitively demanding (Pruitt and Grudin, 2003), for example, increasing users' confusion and decreasing the memorability of personas (Nielsen, 2019).

In particular, the number of personas is associated with the ability to successfully recall details about the personas for task completion. For example, Nielsen (2019) suggests that no more than six personas should be created, as it might be challenging for designers to remember the details of each persona (i.e., the manageability rationale). From an information processing perspective (Song et al., 2021), it is essential that users can recall important details of the personas they are presented with while identifying similarities and differences among them. A higher number of choices in the form of more personas may increase the processing cost of the information due to the limited cognitive capacity of people in general (Wan et al., 2003). Hense, if the cognitive cost of the additional personas is high, any benefits must outweigh this cost.

To investigate these SPH effects, we propose the following RQ and hypotheses:

RQ1: *How does the number of personas affect the users' recall of the persona's information details?*

- **H1:** Employing fifteen personas relative to five decreases the number of persona information details that participants recall. **[SPH]**
- **H2:** Employing fifteen personas relative to five decreases the participants' correctly recalled information about the personas. **[SPH]**
- **H3:** Employing fifteen personas relative to five decreases participants' confidence in recalling persona details. **[SPH]**

Within the persona literature, users' perceptions of personas have been found to be influential for persona acceptance and use in decision making (Probster et al., 2018; Salminen et al., 2018c). We refer to these aspects collectively as 'persona perceptions', as has been done in prior literature (Marsden and Haag, 2016; Salminen et al., 2021a,d), and propose the second RQ:

RQ2: *How does the number of personas affect the users' perceptions of the personas?*

The persona perceptions that we identified as relevant for our study include the *empathy* that a user (i.e., stakeholder) feels towards the persona (Jansen et al., 2020), and the *willingness to use* the persona for a given task (Salminen et al., 2020d; Salminen et al., 2018c). To measure these perceptions, we leverage the *Persona Perception Scale*, an instrument validated in prior research (Salminen et al., 2020d). If the beneficial persona perceptions decrease with the increasing number of personas, that suggests a serious problem and would support a small number of personas. According to this logic, with more personas, stakeholders may feel less empathetic towards them and be less willing to learn about them than when faced with a smaller number that is perhaps less daunting and more intimate. In addition, being presented with a higher number of personas to choose from might create *confusion* for the stakeholders (Kim and Kim, 2001). Confusion has been identified as a risk in previous persona studies (Salminen et al., 2018a,b) , especially pertaining to data-driven personas and persona systems (Salminen et al., 2019; Jung, et al., 2018) that may involve a higher degree of abstraction than conventionally created personas. Thus, more personas may leave users feeling confused. The above reasoning results in the following hypotheses:

- **H4:** Employing fifteen personas relative to five decreases the participants' empathy towards the personas. **[SPH]**
- **H5:** Employing fifteen personas relative to five decreases the participants' willingness to use the personas. **[SPH]**
- **H6:** Employing fifteen personas relative to five increases the participants' confusion about the personas. **[SPH]**

Finally, commonly applied user perceptions in HCI research include task-related aspects such as *motivation, enjoyment*, and *difficulty* (Salminen et al., 2020d; Salminen et al., 2018c). Again, if increasing the number of personas would make these task-focused perceptions worse, this would signify a problem. From the SPH, we expect this to be the case:

- **H7:** Employing fifteen personas relative to five decreases the users' experienced task motivation. **[SPH]**
- **H8:** Employing fifteen personas relative to five decreases the users' experienced task enjoyment. **[SPH]**
- **H9:** Employing fifteen personas relative to five increases the users' experienced task difficulty. **[SPH]**

The measurement items for the perceptions (along with other variables) are presented in the data collection section.

4.2. Big personas hypothesis

Due to the recent evolution in data-driven persona creation methods and interactive persona systems, we also propose an alternative Big Personas Hypothesis or BPH, based on the notion that a novel system-based approach to personas can overcome the presumed issue of too many personas overloading the users' ability to cope with them.

Three specific developments in persona generation and associated technology development lend credence to the BPH, i.e., a counterhypothesis to the SPH postulating that the number of personas *can* be increased with more positive than negative effects. These developments are described below.

First, for system development and design implications, it is crucial to measure how the number of personas affects users' engagement with the personas, including the persona information that the users engage with and the amount of attention they allocate to this information (Negi and Mitra, 2020). To investigate this matter, we address the following RQ, with associated hypotheses:

RQ3: *How does the number of personas affect the users' engagement with the personas?*

- **H10a:** Employing fifteen personas relative to five increases the users' engagement with the available personas, based on the number of gaze fixations. **[BPH]**
- **H10b:** Employing fifteen personas relative to five increases the users' engagement with the available personas, based on gaze dwell time. **[BPH]**

Second, there is a notion that more personas afford capturing more diversity. The pursuit of more personas is particularly compatible with diverse and heterogeneous online end-user populations. Manual persona design can provide rich narratives of user behaviors, but scales poorly to popular big data sources such as social media and web analytics (Stevenson and Mattson, 2019). Online platforms, services, and software can have millions to billions of end-users from hundreds of countries, with different cultures, religions, and languages (Aboelmaged and Mouakket, 2020; Anvari et al., 2019; Lee et al., 2020; Sim et al., 2019; Singh, 2020), and it may be that these populations are too variable to be represented with just a handful of personas. To address this variability, data-driven personas (McGinn and Kotamraju, 2008; Miaskiewicz and Luxmoore, 2017; Mijač et al., 2018; Salminen et al., 2020b; Zhang et al., 2016; Zhu et al., 2019) create opportunities where more personas capture a wider range of demographic subgroups and marginalized end-user demographics and behaviors. In turn, communicating this variability of end-user base to persona users can possibly mitigate any stereotypical thinking (Turner and Turner, 2011) and increase inclusive design outcomes (Goodman-Deane et al., 2018).

To this end, we propose the following RQs and hypotheses:

RQ4: *How does the number of personas affect the demographic diversity of end-user representation?*

- **H11:** Employing fifteen personas relative to five results in a higher demographic diversity of end-user representation. **[BPH]**

RQ5: *How does the number of personas affect the users' choice of personas for the task?*

- **H12:** Employing fifteen personas relative to five results in persona users choosing a more diverse set of personas for a design task. **[BPH]**

Third, we presume that users can efficiently manage more personas via interactive persona systems. UI techniques such as sorting, searching and filtering can allow stakeholders to navigate a large number of personas and select those they need for a given task (Li et al., 2021; Salminen et al., 2020c). Providing navigational features and offering personas via a system rather than a paper sheet, PDF, or PowerPoint presentation may alleviate the cognitive effort stakeholders might face with many personas. Therefore, we ask and propose:

RQ6: *How is user interaction with personas and the persona system affected by the number of personas?*

- **H13:** Employing fifteen personas relative to five results in users paying more attention to navigational system features. **[BPH]**

Together, these trends in persona development motivate testing the 'small number hypothesis' (i.e., that 'fewer than ten' personas are optimal) against a number that is beyond the range, i.e., the BPH (see Section 5.3 for more details).

5. Methodology

5.1. Participants

The data collection site is a large non-profit organization with employees of multiple nationalities, where the study was conducted at the participants' workplace. The organization has used personas for several years (a) to better understand its online social media and other end-users, and (b) for strategic planning, involving crafting agendas to better serve the various stakeholder groups of the organization.

The participants were recruited on a voluntary basis among the organizational departments and job functions involved with user-centric decision making (e.g., communications, public relations, website development, and similar). In total, there were 37 participants, of which ten (27%) were women. The average age of the participants was 32.9 years (SD = 6.9). They represented 18 different nationalities, which stresses the international mission of the non-profit: the United Kingdom (UK), Canada, Germany, Jordan, Libya, France, Qatar, India, China, Algeria, Chile, Philippines, Pakistan, Egypt, Italy, Turkey, Palestine, and Poland. The participants' experience of personas included '*Conceptual experience*' (71%, $n = 26$), '*Some practical experience*' (27%, $n = 10$), and '*Extensive experience*' (3%, $n = 1$). They held various job positions within the organization, such as data analysts, engineers, editors, social media managers, copywriters, project managers, and content specialists – these were categorized into three work roles (see Table 2).

Table 2
Participants of the study.

Gender	No.	%	Work role	No.	%
Male	27	73.0	UX & Marketing	14	38.0
Female	10	27.0	Research	14	38.0
			Software Development	9	24.0
Total	*37*	*100%*	*Total*	*37*	*100%*

5.2. Interactive persona system

An interactive persona system was deployed for this study. This system (the technical details and validation for which has been provided in previous research (An et al., 2018b; An et al., 2018a) allows stakeholders to select and browse their organization's personas, which are generated from the organization's data sources (e.g., Google Analytics, YouTube Analytics, Facebook Insights). The data source deployed here was YouTube Analytics, to which we had access based on the organization's permission and from which the data for persona generation was retrieved using the YouTube Analytics API, adhering to the platform's terms of service and preserving the privacy of individual end-users. Briefly, the personas are based on the engagement of demographic groups in different kinds of YouTube videos of the organization. Using the interactive persona system, these statistics are processed algorithmically using non-negative matrix factorization (Lee and Seung, 1999). The obtained latent patterns are enriched with names, pictures, topics of interest, and quotes, in order to form complete persona profiles. The system enables the creation of 5–15 personas from a data source (S.-G. Jung et al., 2018), and two sets of personas were generated from this range for use in this study.

5.3. Study design

In the user study sessions, participants used the interactive (Berkel et al., 2021) persona system (Jung et al., 2017, 2018a,b) with sets of either five or fifteen personas. The personas represented the organization's YouTube audience and were generated from the organization's YouTube channel analytics data using a data-driven persona generation methodology validated in previous research (An et al., 2018b; An et al., 2018a).

The participants' task was to (a) select one specific persona from the set and (b) craft a YouTube video title and caption that would resonate with the selected persona. These two sets of personas (five and fifteen) were chosen to test the difference between what falls **within** the rule of thumb (i.e., when $n = 5$) and what falls **beyond** the said rule (i.e., when $n = 15$). Additionally, both choices are exactly *five* personas apart from ten, which was found to be a divider between 'fewer' and 'more' personas, based on the literature review (see Section 2).

Fig. 2 shows an example of each condition (the system with five and fifteen personas). Screenshots of all the personas used in the user study are provided in an online appendix (https://www.dropbox.com/sh/gtuopopbqwgxjbw/AABPBK8KByeX2rvo3uOTsGNda?dl=0).
Comparing these two sets, we apply a within-participant design. Each participant was administered both five and fifteen personas, carrying out the same task, while counterbalancing for order effects. We pilot tested the study design with four test subjects who did not participate in the actual study, making minor wording changes to the instructions based on their feedback.

5.4. Procedure

The user study was conducted in the participants' workplace. The study took approximately 40 min per participant, however, we did not limit the participants' time to complete the task and allowed them to spend as much time as they needed. We instructed all participants in the same way at the beginning of the study in regard to using the devices and about the study procedure (see Fig. 3).

To begin each trial, we welcomed the participant, introduced the study (i.e., using eye-tracking to investigate how they use the system), and answered any questions they had. After completing a consent form, each participant was assigned a unique ID and they proceeded to eye-tracking calibration. After this, the participants were shown one of the two persona sets and asked to complete the following design task:

Your task is to promote the [organization] as a workplace to a specific persona. A persona is a fictitious person that describes a real user segment. The personas you will see are created from the real audience data from [organization]'s YouTube channel. They represent [the organization]'s audience segments on YouTube.

The task was designed in collaboration with the focal organization's management to represent a realistic use case, that was doable within the time constraints of the user study, and aligned with most participants' typical work routines. Participants chose one persona from each set they saw for their design task of creating a social media post targeted at that persona. The choice was purposefully narrowed down to one persona in order to obtain a clear choice from the participants, although the participants were in no way hindered in perusing as many personas as they wanted.

Once the participant had selected a persona from the first sequence, they took a survey concerning why they selected that persona, crafted the video title, and ranked on a seven-point Likert scale how confident they were of their responses. At this point, the participant would continue the session with the other set of personas, repeating the selection, survey, message crafting, and rating. Participants conducted the study individually and were free to take as much time as they needed to make a choice, with most participants taking between five and ten minutes to select a persona. The results from a paired *t*-test show that the mean session duration (in seconds) was significantly higher for fifteen

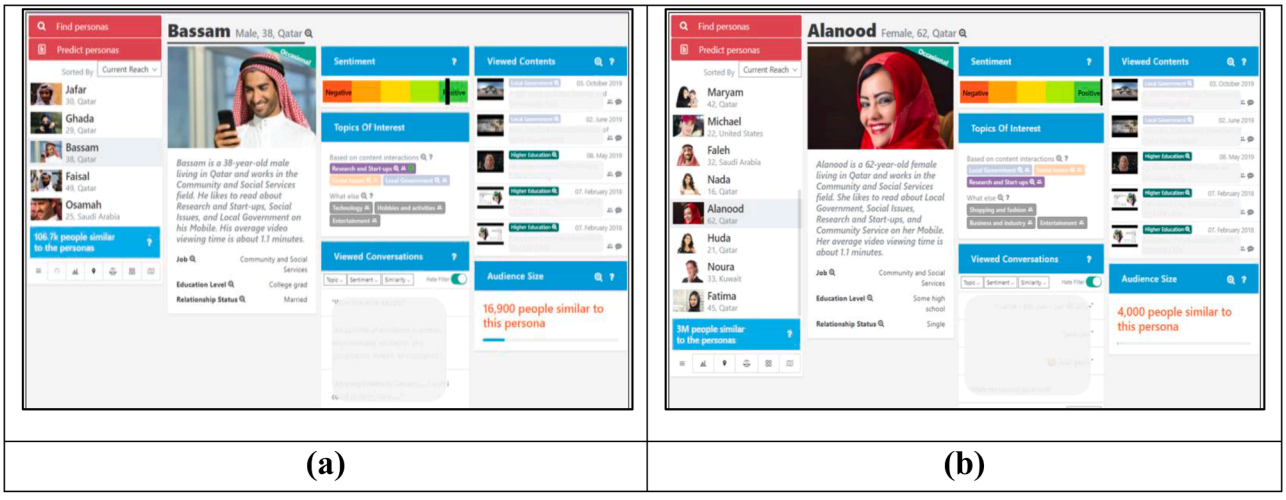


Fig. 2. Screenshots of the system with five personas (a) and fifteen personas (b). Participants could select personas by clicking them on the left sidebar. In the fifteen-persona condition, participants could scroll down. In both conditions, participants could filter and sort the personas. Organizational dentifying content is masked.

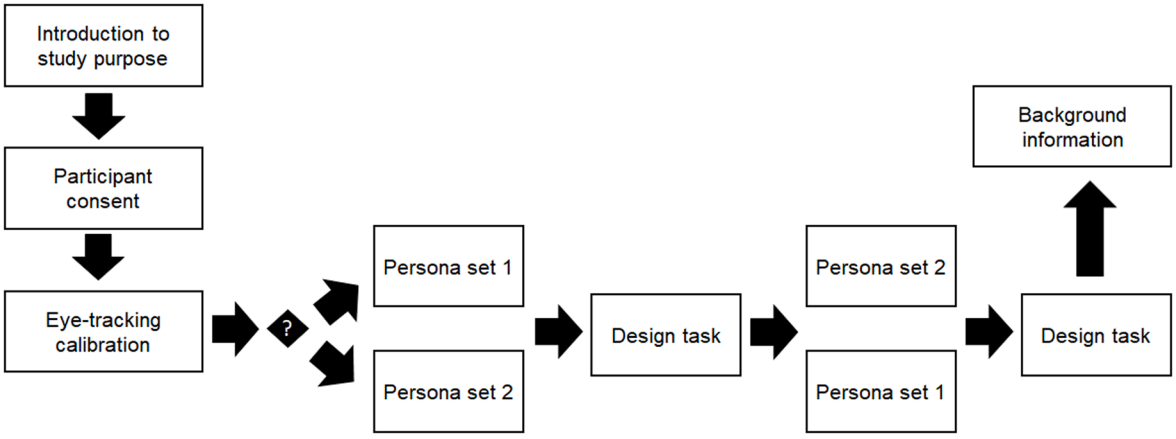


Fig. 3. Study procedure.

personas ($M = 363$, SD = 194) than for five personas ($M = 251$, SD = 141), t(36) = −3.45, $p = 0.001$, which we discuss later in the findings.

Once the participant had completed both sessions on the interactive persona system, they completed a post-questionnaire and a demographic survey. After this, we thanked the participant and addressed any questions they had. The participants were rewarded with a gift card (the equivalent of $27.40) as a token of appreciation.

5.5. Data collection and constructs

To conduct the sessions, we used two identical workstations equipped with a laptop (HP Studio G4 laptops) and external display (HP233 EliteDisplay, 23 in. 1920 × 1080 pixels, 60 Hz refresh rate), a Gazepoint GP3 eye-tracking device (a research-grade eye-tracker utilizing a 60 Hz infrared camera), and associated software for logging the visual engagement of the participants. In addition to furnishing (a) **eye-tracking data** and (b) **survey data**, the complementary data collection modes afforded a solid basis for addressing the RQs. The association between the RQs and data collection is shown in Table 3. The survey measurement items are shown in Table 4.

The hypotheses were tested using appropriate statistical procedures, as explained in the following sections.

6. Results

6.1. RQ1: how does the number of personas affect the users' recall of the persona's information details?

H1 concerns how much information is recalled from the personas, whereas H2 addresses how much of that information is *correctly* recalled. To address H1, we measured how much the participants recalled specific information in the persona profiles via responding to questions in the post-session survey. For this, we manually coded the answers to the open-ended question *"please write as many details as you remember about the personas"* based on whether they contained specific persona information, denoted as Areas of Interest (AOIs). The coding noted how many times a participant referred to each AOI. For example, if participant B01 mentioned the country of two personas when seeing five personas, then $\text{Country}_{B01-5} = 2$, meaning there were two mentions for the participant in the given condition. We then conducted a negative binomial regression to test the differences in counts among five and fifteen personas, based on the data coding explained in the previous section. A mixed model was used to consider the paired nature of the data. An intercept was added to the model to account for excess zeros.

The results show that 18.2% more specific persona information is recalled from five ($n = 182$ information pieces) than from fifteen personas ($n = 154$). However, this difference is not significant (IRR = 1.19, 95% CI 0.64; 1.04, $p = 0.10$). Therefore, **H1 is not supported: There is no statistically significant evidence that employing fifteen personas relative to five would decrease the number of persona details that users recall.**

Table 3
Research questions and associated data collection methods.

	Data Collection Method Employed	
Research Question	Eye tracking	Survey
RQ1: (recall and confidence)	N/A	✓
RQ2: (persona perceptions)	N/A	✓
RQ3: (engagement)	✓	N/A
RQ4: (persona diversity)	N/A	✓
RQ5: (user decisions)	N/A	✓
RQ6: (user interaction with system and personas)	✓	N/A

Table 4
Study variables. Multi-item constructs (*empathy* and *willingness to use*) originated from the Persona Perception Scale (Salminen, Santos, et al., 2020); other constructs were designed to match the research questions. All items were measured using a seven-point Likert scale, ranging from 'Strongly agree' to 'Strongly disagree' and, in the case of Recall confidence, 'Very confident' to 'Not confident at all'.

RQ	Construct	Items
RQ1	H1: Information recall	Computed from survey answers
	H2: Correctly recalled information	Computed from survey answers
	H3: Recall confidence	How confident are you in the answers that you gave about the personas?
RQ2	H4: Empathy	I feel I understood who the personas were as people. I felt strong ties to the personas. I could imagine a day in the life of the personas.
	H5: Willingness to use	The personas seemed useful for my task (of writing the YouTube video title). I would make use of these personas in my task (of writing the YouTube video title). These personas would improve my ability to make decisions about the audience segments they describe.
	H6: Confusion	Viewing the personas felt confusing.
	H7: Task motivation	I was motivated to use the persona system.
	H8: Task enjoyment	I enjoyed using the persona system.
	H9: Task difficulty	I found the task (of writing the YouTube video title) difficult to complete.
RQ3	H10a: Gaze fixations	Eye-tracking variable
	H10b: Gaze dwell time	Eye-tracking variable
RQ4	H11: Demographic diversity of personas	Computed from persona attributes
RQ5	H12: Diversity of user choice	Computed based on persona attributes and users' choice of a persona
RQ6	H13: Attention	Gaze fixations and dwell times on Areas of Interest

Addressing H2, we verified if the previously coded information mentioned by the participants was correct or not by comparing it to the actual information presented in the persona profiles. For example, if one of the mentioned countries in the participant's answers was correct, and one was incorrect, then each was separately noted down in 'correct' and 'incorrect' datasheets. Using this coding, we computed the *correct recall rate* (CRR) for each participant, in order to address H2. Overall, most of the information was correctly recalled (90.5%, $n = 304$ pieces of information), with only 9.5% ($n = 32$) being classified as incorrect. For five personas, the CRR = 93.4% ($n = 182$). For fifteen personas, the CRR = 87.0% ($n = 154$). To test the significance of the difference, we calculated the incident rate ratio (IRR = 15 personas / 5 personas), 95% Confidence Intervals (CI), and p values. The results indicate that although users recall more correct information from five than from fifteen personas (IRR = 0.70, 95% CI 0.45; 1.1), this difference is not statistically significant ($p = 0.122$). Therefore, **H2 is not supported: There is no statistically significant evidence that employing fifteen personas relative to five would decrease the participants' ability to correctly recall information about the personas.**

To address H3, we first investigated the users' self-reported confidence ratings regarding the recalled information and the task output by conducting a paired *t*-test. The recall confidence decreases only to a little degree (−1.0% when comparing the score changes between fifteen and five personas), and the difference is not significant, $t(36) = -0.30$, $p = 0.77$. Similarly, the task confidence for five personas ($M = 5.76$) is not higher than for fifteen personas ($M = 5.57$), $t(36) = 1.36$, $p = 0.181$. Thus, **H3 is not supported: There is no statistically significant evidence that employing fifteen personas relative to five would decrease the confidence of the recalled persona details.**

6.2. RQ2: how does the number of personas affect the users' perceptions of the personas?

We conducted paired t-tests to compare changes in the persona perceptions concerning empathy (H4), willingness to use (H5), and confusion (H6). There was no significant decrease in the empathy scores reported for fifteen personas ($M = 4.42$, SD = 1.32) relative to five personas ($M = 4.74$, SD = 1.35), $t(36) = -1.69$, $p = 0.10$. Similarly, there was no significant decrease in willingness to use fifteen personas ($M = 5.78$, SD = 1.20) relative to five personas ($M = 5.83$, SD = 1.11), $t(36) = 0.27$, $p = 0.79$. Finally, there was no significant increase in confusion reported for fifteen personas ($M = 3.03$, SD = 1.79) relative to five personas ($M = 2.65$, SD = 1.58), $t(36) = -1.16$, $p = 0.25$. Therefore, **H4 (empathy), H5 (willingness to use), and H6 (confusion) are not supported: There is no statistically significant evidence that employing fifteen personas relative to five would decrease the participant's empathy towards or willingness to use the personas, or the users' confusion regarding them.**

We then tested the user experience perceptions. For this, we conducted paired t-tests to compare changes in motivation (H7), enjoyment (H8), and difficulty (H9). There was no significant decrease in task enjoyment reported for fifteen personas ($M = 6.05$, SD = 0.87) relative to five personas ($M = 6.00$, SD = 0.93), $t(36) = -0.36$, $p = 0.72$. Similarly, there was no significant decrease in task motivation reported for fifteen personas ($M = 6.24$, SD = 0.75) relative to five personas ($M = 6.27$, SD = 0.79), $t(36) = 0.20$, $p = 0.84$. Finally, there was no significant decrease in task difficulty reported for fifteen personas ($M = 3.00$, SD = 1.70) relative to five personas ($M = 2.95$, SD = 1.60), $t(36) = -0.17$, $p = 0.87$. **Therefore, H7 (motivation), H8 (enjoyment), and H9 (difficulty) are not supported: There is no statistically significant evidence that employing fifteen personas relative to five would decrease task motivation and enjoyment, or increase task difficulty.**

6.3. RQ3: how does the number of personas affect the users' engagement with the personas?

We measured two metrics of engagement: the number of fixations (H10a) and dwell time (H10b). The first is the number of times a user's eyes fixate on a specific point on the screen, indicating that the user is 'pausing' their gaze. The second measures the amount of time (in seconds) a user spends with the system. Together, these metrics measure some of the various aspects of user engagement when using a computational system (Duchowski, 2009; Gwizdka and Cole, 2013; Salminen et al., 2018a).

We conducted paired t-tests to compare the means of dwell time and the number of fixations between five and fifteen personas' conditions. Both the dwell times ($D = 0.12$, $p = 0.20$) and fixation counts ($D = 0.09$, $p = 0.55$) passed the Kolmogorov-Smirnov test for normality (D in parentheses is the metric of this test), which is a requirement for using the *t*-test (Parab and Bhalerao, 2010). The results indicate that more time is spent with fifteen personas ($M = 363.5$ s, SD = 197.2) than with five personas ($M = 251.2$, SD = 143.2), $t(35) = -3.45$, $p = 0.01$. Similarly, there were more fixations for fifteen personas ($M = 955$ fixations, SD = 485) than for five personas ($M = 676$, SD = 391), $t(36) = -3.3$, $p = 0.02$. Therefore, **H10b and H10b are fully supported: Employing fifteen personas relative to five increases the user engagement with the persona system to a statistically significant degree.** Fig. 4 illustrates the differences.

This finding applies for the *total* number of fixations and *total* duration over the whole session (i.e., the sessions of using the personas become longer). However, what happens to *per* persona interaction? We can address this question by examining the fixations and dwell time by persona. This examination shows that the personas in the five-persona condition receive more fixations ($M = 135.1$, SD = 78.1) than the personas in the fifteen-personas condition ($M = 63.7$, SD = 32.3), $t(36) = 5.79$, $p < 0.001$. On average, the five personas also garner more dwell time ($M = 50.3$ s, SD = 28.2 s) than fifteen personas ($M = 24.2$ s, SD = 13.0), $t(36) = 5.89$, $p < 0.001$. These large differences indicate that participants cognitively adapt (Nakayama and Wan, 2021) when processing information about more personas, by spending less time per persona, but spending more time with the personas overall.

Moreover, by quantifying the marginal increase in engagement, we can observe that when the number of personas increases by 200% (from five to fifteen), engagement increases by 43.3% (see Fig. 5), which is **4.3% per additional persona** (there are ten personas more in fifteen personas relative to five). In terms of task performance, the decrease in the correct recall persona information is only **−0.68% per additional persona** [$(CRR\_15pers - CRR\_5pers)/CRR\_5pers = -0.68\%$] – in other words, negligible in this context. Together, these results imply that with more personas, there is no statistically or practically significant cost of not being able to recall as correct details about the personas whether using five or fifteen personas.

6.4. RQ4: how does the number of personas affect the demographic diversity of end-user representation?

We investigated the question of persona diversity by analyzing the demographic composition of the generated personas when changing the hyperparameter that controls the number of personas. Both persona sets were generated from the same real end-user data of the organization using the same algorithmic process, as explained in the method section. The hypothesis was that more personas would be demographically more varied, i.e., more representative of the actual end-user base, than fewer personas. Fig. 6 illustrates the personas that the data-driven system generated, and Table 5 includes the demographic information.

The age range among fifteen personas (range = 46 years, min = 16, max = 62) is considerably higher than among five personas. This is particularly impactful, because the small number of personas "cuts" out the younger (16-year-old Nada) and more elderly (62-year-old Alanood)

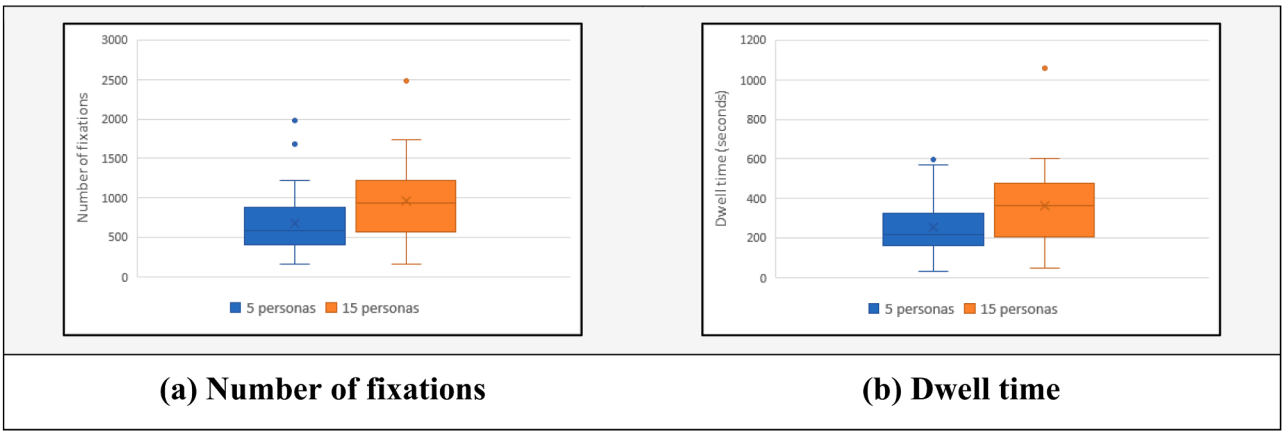


Fig. 4. Boxplots of fixations and dwell time. Both are higher for fifteen personas relative to five personas.

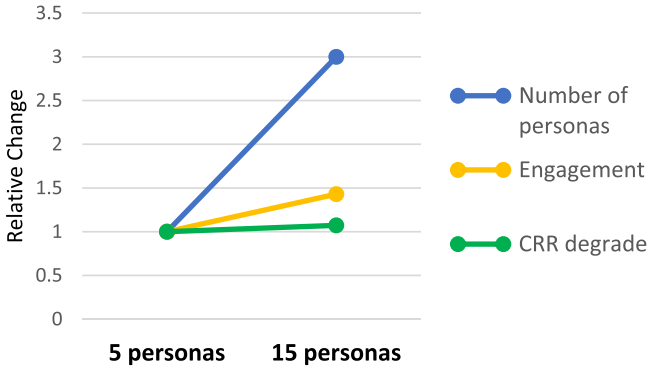


Fig. 5. Change of metrics, standardized relative to the baseline of one. Engagement is a macro-average of dwell time and fixations. CRR degrade is inverse of the standardized CRR value, indicating a 'worsening' task performance. Engagement (yellow line) increases less than the number of personas. Task performance (green line) degrades only a negligible amount.

personas that appear in the more personas set. The fact that the mean age remains relatively stable ($M = 34.2$ years for five personas and $M = 32.9$ for fifteen) implies that in both cases, the algorithm finds the central tendency in the data, but in the more personas condition it expands this central tendency into narrower demographic end-user groups, thereby increasing the representativeness of the end-user representation.

In terms of gender, only one out of five personas (20%) is female in the five personas set. However, in the fifteen personas condition, eight out of fifteen personas (53%) are female. It is unclear as to why the algorithm produces such a drastic change of ratio, but it might relate to the fact that generating only five personas may involve a degree of statistical randomness that caused the five personas to be male – that is, nearly each time, out of two possible genders (note that the baseline data only has two genders, as this is the gender classification used in YouTube Analytics), the algorithm picks male. When the algorithm gets to do more "picks" with fifteen personas, the results become more balanced in terms of gender proportion. For five personas, four of them were Qatari (which is correct because the organization operates in Qatar and the audience consists mostly of viewers from Qatar), and one is from Saudi Arabia. In the fifteen personas set, the number of countries doubles, and includes the United States and Kuwait.

Overall, the results indicate that age diversity, gender diversity, and country diversity are all substantially higher with the larger persona set. Therefore, **H11 is supported: Employing fifteen personas relative to five results in a higher demographic diversity of end-user representation.**

6.5. RQ5: how does the number of personas affect the users' choice of personas for the task?

Here, we inspect the demographic composition of the personas that the participants chose for the design task. The choice of personas has ramifications of inclusivity and diversity of designs, where the chosen personas represent end-user segments whose needs are considered for a given task. We specifically focus on gender, age, and country statistics, as these attributes are commonly used in persona profiles.

6.5.1. Gender

Regarding gender; using the five personas, the personas selected for the design task are almost exclusively male (81.1%, $n = 30$). Only in seven cases (18.9%) did a study participant selected a female persona. Using the fifteen personas, the situation changes. Female personas are selected more often (56.8% of times, $n = 21$), whereas male personas are selected sixteen times (43.2%). A Chi-square test of independence shows that there is a significant relationship between the two variables. Users were more likely to choose female personas among the fifteen personas, X^2 (1, $N = 74$) $= 11.3$, $p < 0.001$. Fig. 7 illustrates this effect.

This result can be explained as a consequence of the higher inclusion of females in the generated personas when their number is increased. Fig. 8 shows that the increase in the proportions of the presented and chosen female personas are almost perfectly correlated. In other words, user choices for design seem to mirror the available personas, which is readily understandable. However, the reason why the number of females increased in the persona set when generating more personas is not immediately evident, but there are general mathematical grounds to presume that when increasing the number of personas, more demographic "slots" become available to be filled by various demographic attribute values, and hence diversity increases as an effect of the higher number.

6.5.2. Age

Concerning the chosen personas' age, Fig. 9 shows the distribution of the ages of personas chosen by the participants for the design task. A couple of observations follow. First, the younger demographics (age groups 13–17 and 18–24) were not available among five personas (i.e., the algorithm did not generate personas from these age groups), and therefore they could not have been chosen by the participants. Interestingly, there was one persona in the fifteen personas set of the age group 55–64 (Alanood, 62 years old), but none of the participants selected this persona. Neither persona set included personas above 65 years of age, which implies that even though the demographic coverage of different age groups seems to increase, fifteen personas were not enough to include the rarest demographic groups (there were actual end-users from the 65+ age group in the baseline data). This insight

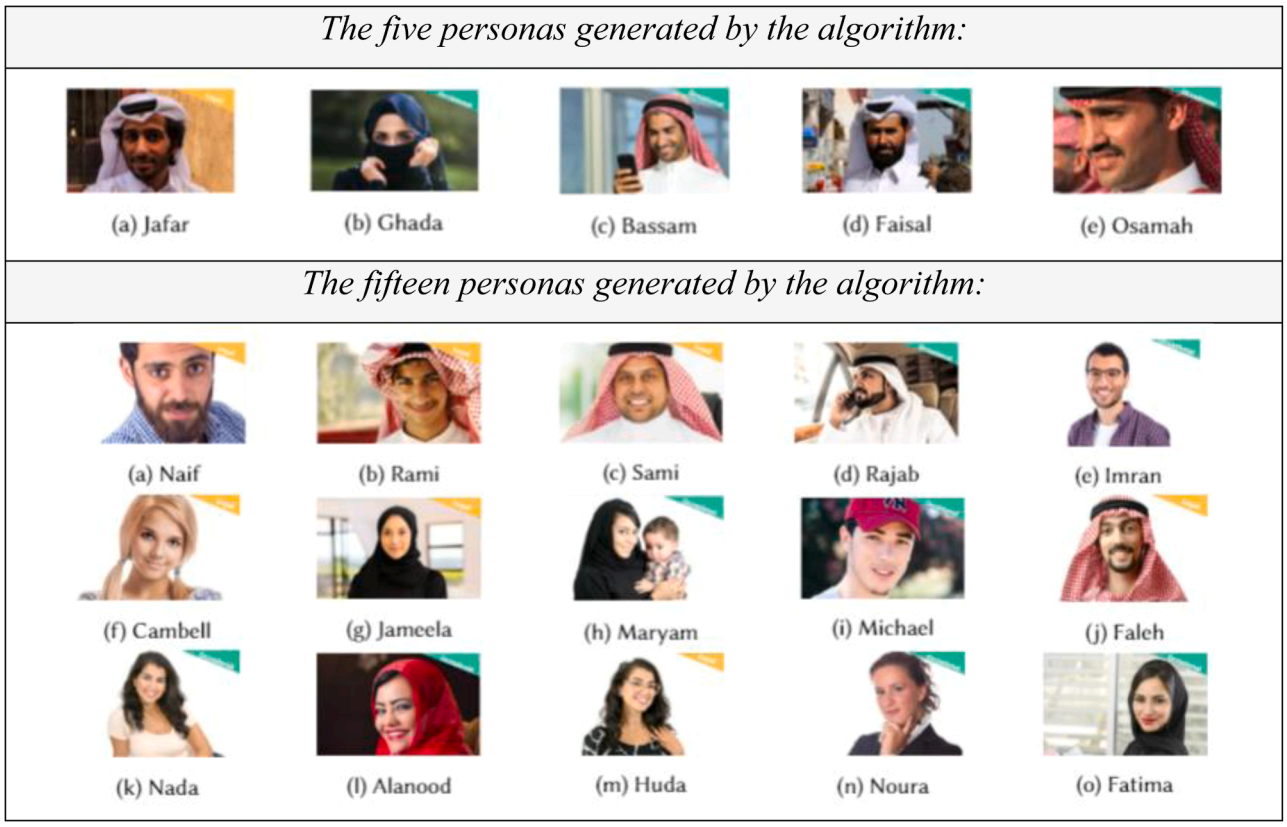


Fig. 6. Illustration of the sets of generated personas (5 and 15 personas).

Table 5
Demographic information about the generated personas.

	5 personas set	15 personas set
Mean age (SD)	34.2 (8.5)	32.9 (11.7)
Age range	13 (25…38)	46 (16…62)
Female-to-male ratio	20.0%	53.3%
Unique countries	2	4

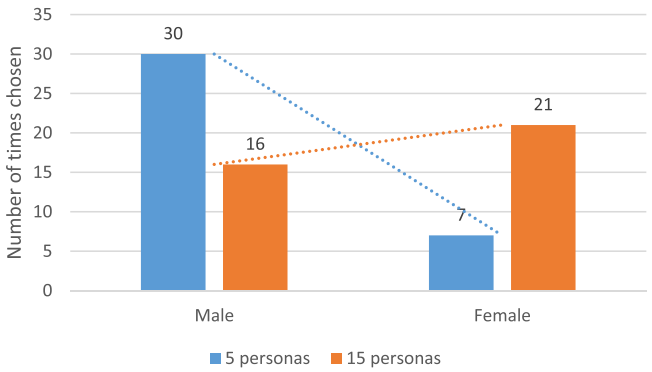


Fig. 7. Gender of the chosen personas in different sets.

implies that, at least for this dataset, even more than fifteen personas may be required to fully represent this end-user population.

Second, the polynomial graphs show a tendency of younger personas being selected among the fifteen personas (see the red line peaking earlier in Fig. 9 than the blue line). This observation is confirmed by a paired *t*-test indicating that participants selected younger personas from the fifteen personas set ($M = 30.3$ years) than from the five personas set ($M = 34.4$), $t(36) = 2.89$, $p = 0.003$. However, whether younger or older personas were selected does not address the proposed hypothesis, which was about demographic diversity. To that end, we examine the *standard deviation* (SD) of the personas' age. SD is a measure of statistical dispersion, which in this context translates to diversity where a higher dispersion in the personas' age implies that more diverse ages were selected. Table 6 shows the SD values in the actual persona set (i.e., baseline) and in the chosen personas.

Two observations can be made: first, the age diversity (i.e., statistical dispersion measured as SD) increases by 37.4% when comparing fifteen personas to five personas, which is a considerable degree. Second, the diversity of the chosen personas' age also increases by 6.8%, but if we normalize this effect by the change in the baseline age diversity (i.e., in the change of age dispersion between five and fifteen personas which, as stated, was more than 30%), the obtained numbers show that the "gain" in age diversity is in fact fairly small (illustrated in Fig. 10). The results can be confirmed by calculating other metrics of diversity. As an example, we also computed Shannon's Diversity Index (H). In this calculation, the selected personas were grouped by age into seven age groups (13–17, 28–24, 25–34, 34–44, 45–54, 55–64, 65+), and H was computed separately for personas selected among five and fifteen available personas. The results indicate a higher age diversity for fifteen personas ($H = 1.42$) than for five personas ($H = 1.26$), although this calculation conducts no statistical significance comparison, nor are the obtained numbers directly comparable in real terms.

6.5.3. *Country*

Finally, we compared the country diversity among the personas chosen by the participants for the design task. As can be seen from Table 7, there are no personas chosen from the US or Kuwait in the five personas condition, simply because these personas did not exist in the set, and hence could not have been chosen. But as soon as the personas from these countries become available, users start selecting them for the design task, as further illustrated in Fig. 11. This drastically alters the

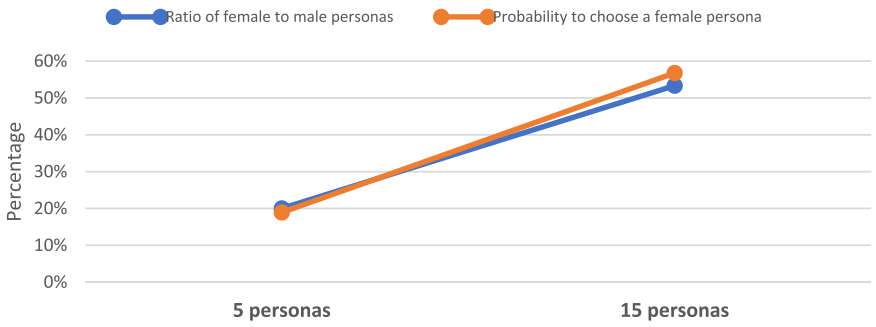


Fig. 8. The correlation between the ratio of females among the personas (i.e., the share of personas in the generated persona set) and the probability of choosing a female persona are almost perfectly correlated ($r = 1$).

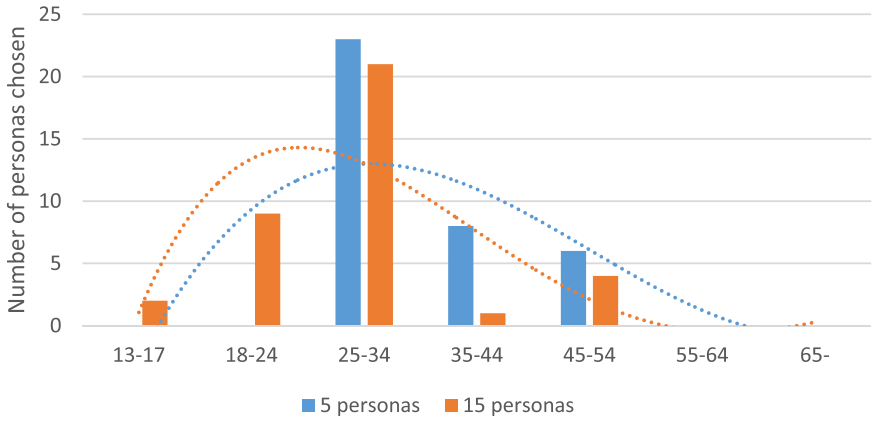


Fig. 9. Age distributions of the selected personas.

Table 6
Standard deviations (SD) of persona ages (in years). SD measures statistical dispersion, which we conceptually associate with diversity – in other words, the higher the SD, the more diversity a persona set's age involves.

	5 personas	15 personas	Delta
$SD_{baseline}$	8.52	11.71	+37.4%
SD_{chosen}	7.42	7.92	+6.8%
SD $fraction_{chosen/baseline}$	0.87	0.68	

distribution of the chosen personas' countries, providing evidence that the diversity of the personas in terms of the personas' country of origin increases when more personas are presented to users.

Because the frequency of the personas' countries differs in the baseline dataset, we can carry out another type of analysis that considers this variation. Out of the five personas shown, four were Qatari, and one was Saudi-Arabian. This sets the expectation of statistical parity to Qatar = 4 / 5 = 80%; in other words, if the participants' choices

Table 7
Countries of the personas chosen for the design task.

	5 personas	15 personas
Qatar	35 (94.6%)	17 (47.2%)
Kuwait	0 (0%)	12 (33.3%)
United States	0 (0%)	6 (16.7%)
Saudi Arabia	2 (5.4%)	1 (2.8%)

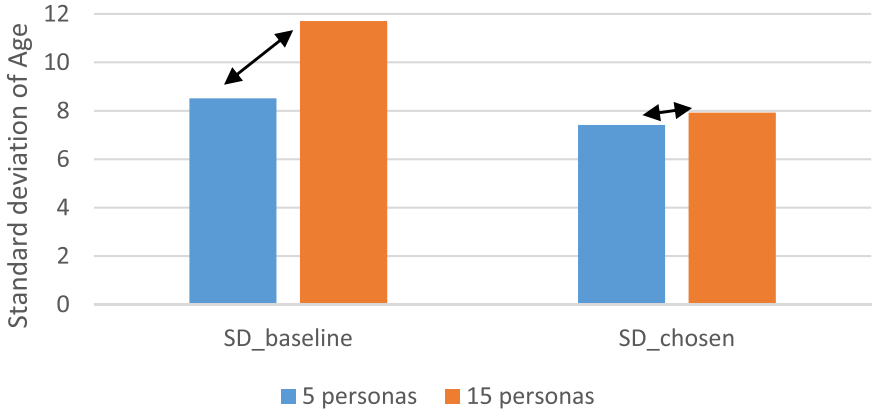


Fig. 10. The standard deviation of ages in the persona sets (SD baseline) and in the chosen personas (SD chosen). The arrows indicate that the diversity of persona ages increases more in the baseline than in the chosen personas.

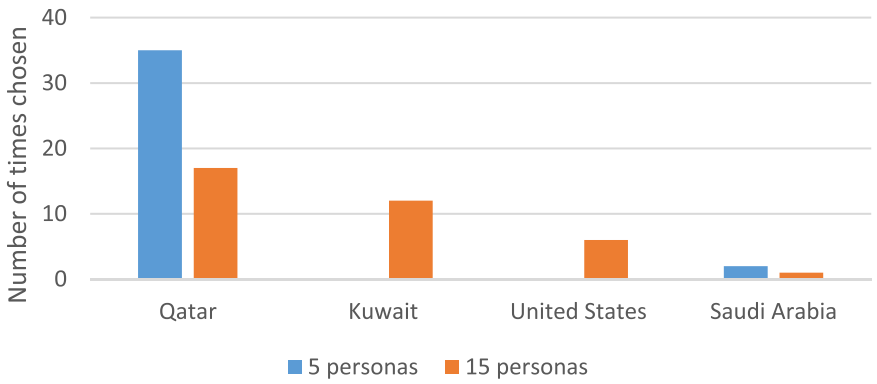


Fig. 11. Countries of the chosen personas.

perfectly mirrored the data, this is the distribution we would expect to see. Yet, what we actually observe is that the Qatari personas are over-represented in the selection (+18.3% relative to statistical parity) and the Saudi personas are under-represented (−73.0% relative to statistical parity). As a sidenote, this cannot be explained by "own nationality preference", i.e., the fact that the participants would be Qatari, because as explained in the method section, the study participants originated from 18 countries, and only 4 (10.8%) were Qatari.

Regarding the fifteen-persona set, the average absolute deviation (AAD) from the baseline countries of the fifteen shown personas is higher at AAD = 65.6% (for the five-persona set, the AAD = |18.3| + |−73.0| / 2 = 45.65%). This implies that the choices in the fifteen-persona set mirror *less* the shown personas than was seen in the five-persona set. While we can only speculate as to what explains the difference, a potential explanation is that the persona user's individual preferences are better revealed with more personas; i.e., a complex reasoning behind which persona is selected and why becomes more influential.

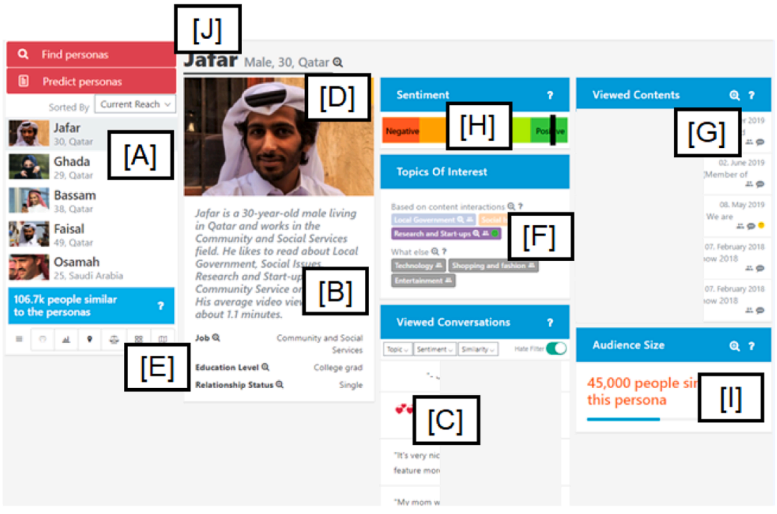
The conclusion of these comparisons is that **there is support for H12; and the collective evidence suggests that employing fifteen personas relative to five results in persona users choosing a more diverse set of personas for a design task.**

It must be noted that, while in all cases (for gender, age, and country), the diversity of the personas chosen for the design task increased with more personas, this effect likely originates from the persona sets themselves becoming more diverse, as concluded in relation to H11. Therefore, the effect cannot be directly attributed to the increase of personas *per se*; but rather, the process seems to indicate: *more personas → more diversity in the persona set → more diversity in the user choices.*

6.6. RQ6: how is user interaction with personas and the persona system affected by the number of personas?

We performed a series of Chi-square tests of independence to examine the relationship between the number of personas (five and fifteen) and each AOI (number of gaze fixations in the AOI and all other AOIs). The results in Fig. 12 show that six AOIs out of ten (Navigation, Description, Quotes, Topics, Contents, and Sentiment) are focused on in a different way among the five and fifteen persona sets. Four out of ten AOIs (Picture, Sociographics, Audience size, and Name) are not focused on in a different way.

More specifically, participants are more likely to view *Persona Navigation* with fifteen personas than with five personas, X^2 (1, N = 37,905) = 117.5, $p < 0.001$. They are also more likely to read the description with fifteen personas than with five personas, X^2 (1, N = 37,905) = 13.7, $p < 0.001$. Finally, *Sentiment* has more fixation for fifteen personas than with five personas, X^2(1, N = 37,905) = 17.1, $p < 0.001$. However, there are more fixations for five personas than fifteen personas in *Quotes,* X^2(1, N = 37,905) = 104.5, $p < 0.001$; *Topics of interest,* X^2(1, N = 37,905) =



		Personas	
	AOI	5	15
[A]	NAVIGATION**	22 %	27 %
[B]	DESCRIPTION**	17 %	19 %
[C]	QUOTES**	19 %	15 %
[D]	PICTURE	11 %	11 %
[E]	SOCIOGRAPHICS	9 %	8 %
[F]	TOPICS**	8 %	6 %
[G]	CONTENTS**	8 %	6 %
[H]	SENTIMENT**	3 %	4 %
[I]	AUDIENCE SIZE	2 %	2 %
[J]	NAME	1 %	1 %
	**Significant at a=0.01 (X^2)		

Fig. 12. Number of gaze fixations on Areas of Interest (AOIs) representing the persona profiles. Color coding indicates a greater relative share of total fixations (denser green is more). Organizational identifying content masked.

38.3, $p < 0.001$; and *Persona's most viewed content,* $X^2(1, N = 37{,}905) = 35.3$, $p < 0.001$.

We also observed this tendency during the user study, where several participants appeared to use the demographic information shown in the navigation to compare the personas and facilitate the completion of their tasks. The persona navigation presents a high-level overview of a persona's key demographics, name, and picture (see [a] in Fig. 12), which supports the rapid skimming of many personas.

The fact that participants focus on *Persona Navigation* and *Persona Description* (i.e., the summary text description of the persona) is compatible with a behavioral pattern in which the users skim through the persona's summary information, then switch to another persona, again skim through the description, and so on. Indeed, this behavior was observed among the participants (see Fig. 13). Viewing the persona's sentiment also belongs to this skimming behavior, where sentiment is most likely used as a snapshot information piece due to its salience on the UI (large, colorful element in a central location).

H13 deals with the impact of navigational features on user behavior. In this light, we focus on the fact that *Persona Navigation* is looked at considerably more often with fifteen personas (this is the sidebar that users can access to scroll through the personas and view their basic demographic information and picture rapidly). The fact that the participants use *Persona Navigation* much more often with fifteen personas than with five personas implies that more personas seems to enhance the navigational use of the persona system. Therefore, **H13 is supported: Employing fifteen personas relative to five results in users paying more attention to navigational system features, specifically Persona Navigation (see Chi-square test results in Fig. 12).**

This seems to come at the cost of spending less time viewing other information, including *Quotes, Topics*, and *Contents*. Hence, there are grounds to argue that more personas affect users to change their information viewing patterns, and as a result, seem to represent an information processing trade-off in which less time is spent with detailed persona information, in favor of navigational and snapshot-type of information (i.e., *Persona Navigation, Text Description*, and *Sentiment*).

6.7. Summary of results

In summary, the results (see Table 8) suggests that users can cope with more personas, and as such, the findings provide more support for the BPH than for the SPH. The results show that using more personas did not decrease the users' ability to recall information about the personas, the rate of correctly recalling information, or their confidence in the recalled information. More personas did not affect empathy, willingness to use the personas, or confusion about the personas. The perceived enjoyment, experienced difficulty, and motivation regarding the task were also not affected by the number of personas.

Table 8
Results of hypothesis testing and implications. ✓ = Fully supported; ± = Partially supported; ✘ = Not supported.

	Result	Implication
The small personas hypothesis		
H1	✘	There is no evidence that employing more personas would decrease the amount of information users recall about the personas.
H2	✘	There is no evidence that employing more personas would decrease the users' ability to correctly recall information of the personas.
H3	✘	There is no evidence that employing more personas would decrease the users' confidence of the recalled persona details.
H4	✘	There is no evidence that employing more personas would decrease the users' empathy towards the personas.
H5	✘	There is no evidence that employing more personas would decrease the users' willingness to use the personas.
H6	✘	There is no evidence that employing more personas would increase the users' confusion of the personas.
H7	✘	There is no evidence that employing more personas would decrease the users' task motivation.
H8	✘	There is no evidence that employing more personas would decrease the users' task enjoyment.
H9	✘	There is no evidence that employing more personas would decrease the perceived task difficulty.
The big personas hypothesis		
H10	✓	**Employing more personas increases the engagement with the personas as a whole (based on both eye fixations and dwell time).**
H11	✓	**Employing more personas increases the diversity of the end-user representation in terms of demographic attributes.**
H12	✓	**Employing more personas increases the diversity of personas that users choose for a design task.**
H13	✓	**Employing more personas results in users focusing more on navigational features that help cope with the additional personas.**

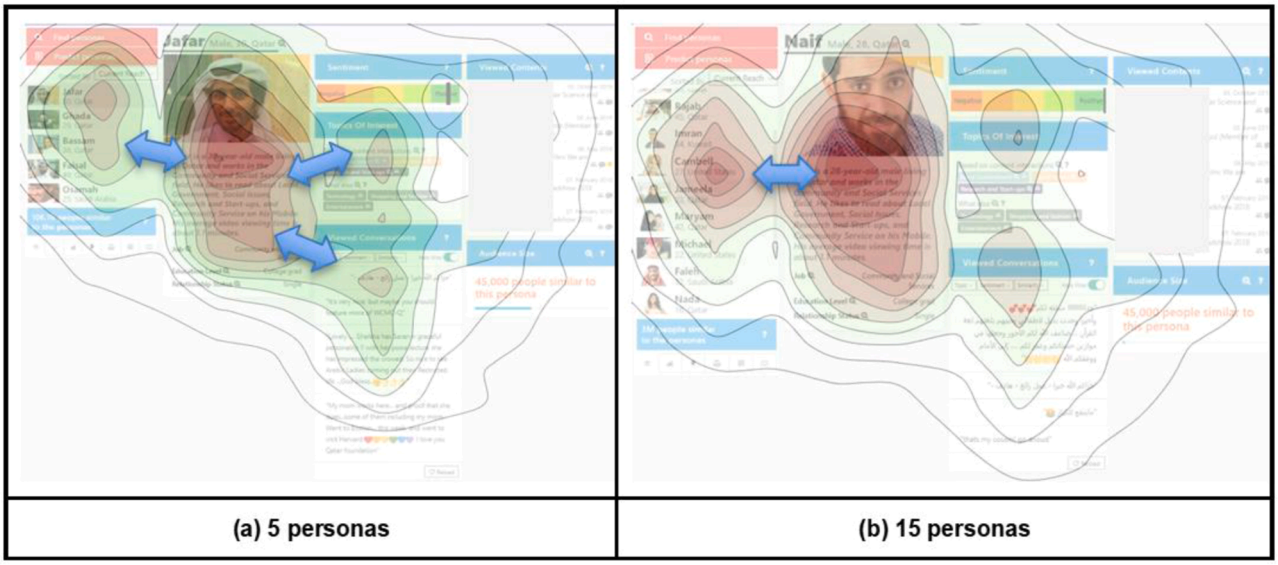


Fig. 13. Contour maps showing the number of fixations in the persona profiles (a darker color indicates more fixations than a lighter color). For fifteen personas, there is a tendency to fixate on the text description and persona navigation (illustrated by the arrow), whereas, for five personas, there is this same behavior, but the users also spend more time in other elements of the persona profile. Organizational identifying content is masked.

In contrast, the users' level of engagement was higher with more personas; more personas resulted in more diverse user representation; and the users' chose personas with more varied demographics when using more personas. In addition, users used more navigational features to cope with more personas, and exhibited more efficient information-processing behaviors.

7. Discussion

7.1. Research contributions

Our findings contribute to the body of knowledge in the domain of persona science; i.e., the study of the creation and employment of personas based on insights identified via scientific analysis of empirical user behavior. Particularly, the findings contribute to two lines of HCI research: (1) persona user behavior, and (2) persona design theory. Both are discussed separately in the following subsections.

7.1.1. Contributions to persona user behavior research

Previous studies presume (either implicitly or explicitly) that a trade-off generally occurs between the number of personas and their usability (i.e., in terms of cognitive cost). However, this premise has not been tested empirically in order to truly understand persona user behavior. To address this gap, our findings reveal insights into user behaviors when the number of personas is increased beyond the traditional amount of "less than ten".

The outcome of engagement increasing relatively less than compare to the number of personas used can be explained by the fact that users tend to adopt efficient information-processing strategies such as satisficing (Adamowicz and Swait, 2013; Simon, 1956), that minimize cognitive effort and maximize the information inferred from the personas, given bounded rationality. In other words, when asked to choose a persona for a professional task, *users flexibly adapt to the changing number of personas* by using the system's navigational features to their advantage – they quickly skim the essential information from the personas when there are more personas but take more time per persona when fewer are presented. Thus, the findings imply that *users spend their time more efficiently with more personas*.

Regarding users' adaptation to the number of personas, a distinct behavior for fifteen personas is that *users focus on persona navigation and text description so as to more quickly scan through more personas*. Therefore, users are seemingly able to cope with the increase in number of personas by inferring a similar amount of information about the personas in a shorter time, which again implies that users' cognitive strategies work towards processing persona information more efficiently when the number of personas is higher. This process is facilitated by interactive features that make it faster to browse personas and to switch between them for comparison and choice.

Overall, we did not find any significant drawbacks in having more personas. The users' recall of persona details stays the same, so do their central persona perceptions. There is no increase in confusion, and no decrease in confidence concerning task completion, nor in their empathy towards personas or their willingness to use them. Furthermore, on the positive side, users' engagement with the personas increases with more personas, and more personas result in a more demographically diverse set of personas. Users leverage this diversity by choosing more diverse personas for a design task, and they are able to adjust their behaviors to make use of interactive features for browsing and comparing the personas when finding a persona to design for.

7.1.2. Contributions to persona design theory

Another line of HCI work towards which this study contributes is persona design theory and persona science, in which the question of the 'right' number of personas has raised nearly as many viewpoints as there are authors. Cooper's original recommendation to focus on one main persona (Cooper, 2004) might implicitly assume that the more time one spends with a persona, the better, because more time implies that the persona user is engaged and is learning about the persona. However, the findings from this research suggest that this is not the case – users did not learn significantly more from five personas than from fifteen personas for the same task. This result leads us to suggest that *the SPH is outdated in an age of interactive persona systems*. This is because digital end-user data and data science algorithms not only enable choosing the number of personas in a quick and easy way (i.e., by varying a hyperparameter that can be done with a click of a button), but also offer search and filter functions for users to narrow down the final set of personas (or even just one persona) for the task at hand.

Keeping the number of personas low is understandable when the persona medium is paper or an equivalent, as it would be challenging to manage dozens of sheets or slides, each representing a different persona. By using interactive persona systems and digital end-user data, it is possible to overcome this 'trap of paper' as the default choice of medium for personas, and is particularly useful for comparing and choosing between personas. When provisioning data-driven personas via digital UIs, the underlying end-user data can also be made available as a download for numerical analyses (Jansen et al., 2020).

The results concerning the demographic diversity of personas chosen for design purposes can be explained so that users' persona choice is strongly influenced by the available personas. Put simply, if persona developers show more female personas, then more female personas are chosen for the design task. Coincidentally, this is exactly what inclusive design seeks to accomplish – the use of a more diverse persona set by increasing persona set diversity (Goodman-Deane et al., 2018). Therefore, when the persona developers' goal is to increase the persona user's knowledge of the diversity of the end-user base, it makes sense to show more personas.

Nonetheless, we must be careful with the generalizability of this claim because diversifying the user choices depends on more variety actually appearing in the persona set, which cannot be guaranteed when using a data-driven persona creation approach, as it is the algorithm that ultimately selects the personas' traits. In our study, the "collaboration" between the data and the algorithm yielded more diversity with the increase of personas, but in other cases, this outcome could be different. For data-driven personas, the attributes in the persona set correlate with the bias/skewness of the data and the applied algorithm's consideration of the properties of the data (Salminen et al., 2020a).

Finally, even when one designs just for one to three personas (Nielsen, 2019), it seems reasonable that the *entire* set of possible personas in the design space should reflect the underlying segments of the end-user population. Otherwise, researchers and practitioners needlessly limit their perspective while setting themselves up for the (perhaps pleasing but misguided) fallacy that only a few personas are needed to understand the end-user base satisfactorily. In the experimental design process (Anvari and Richards, 2018), it may be difficult to handle many different end-user groups simultaneously, but one nonetheless needs to know about various end-users for testing designs.

7.2. Design implications

The decision regarding the number of personas is nontrivial. Overall, our results suggest that, at least when using an interactive persona system, users can manage more personas than conventionally recommended. Therefore, more personas (at least as many as fifteen) can be created, with the possible caveat of using an interactive persona system.

As with most design choices, there are advantages and disadvantages to having fewer or more personas. One should create *more personas* when wanting to (a) present different end-user types in the data; (b) give plenty of choices that allow users to select their personas freely from a wide variety; and are (c) able to offer users efficient techniques to filter and navigate the personas. However, one should create *fewer personas* when wanting users to examine each persona carefully using the maximum time.

Specifically for data-driven personas that portray heterogeneous end-user populations (e.g., social media and online audiences), we advocate *creating more than ten personas to cover different behaviors and demographics that occur in one's end-user data*. Users are able to capitalize on interactive features to spend their time more efficiently with more personas. So, even though the dwell time per persona decreases, the users' ability to recall personas or correctly recall information about them does not decrease.

For the design of interactive persona systems, it is particularly important to *provide easy controls for persona navigability*. Our results indicate that when the participants were exposed to more personas, they focused on the navigational sidebar considerably more than when exposed to fewer personas. Navigation plays a central role in overcoming the manageability problem of more personas, and using a navigational bar is efficient because it provides a snapshot overview of each persona's basic attributes (picture, name, age, country) that act as informational cues for users' persona exploration. The significantly higher use of navigation seen in our results supports the notion that interactive techniques are necessary to support users as the number of personas increases.

7.3. Limitations and future work

As with most research, there are limitations to the presented study. First, when relying on the statistical tests alone, one cannot say that increasing the number of personas does not affect the constructs measured in relation to the SPH (due to the possibility of false negatives). However, the multiple hypotheses tested show no significant adverse effect when using a larger number of personas, and these multiple analyses all arriving at similar non-significant findings gives credence to the idea that 'more personas is okay'.

Second, we did not randomize the initial ordering of the personas in the navigation. The participants could use the filter and search functions of the system, but most clicked from one persona to another using the left-side persona navigation panel. As research into navigation is a domain in itself, we thought it best to avoid this mitigating effect and deploy the persona system as it actually exists. As such, the presentation order of personas to participants is an area for future research.

Third, we did not specifically target only designers when recruiting the participants. This choice stems from the fact that personas are used in many professions (Goodman et al., 2007), including those dealing with marketing, content creation, public relations, and so on (Almahri et al., 2019; Clarke, 2015; Revella, 2015). In these professions, personas aid content and communication design. However, a user study conducted only among UX/UI/interaction designers might be interesting, as there may be task dependencies affecting the 'right' number of personas for given design tasks.

Fourth, we tested a specific persona template / layout. Even though the template we tested approximately corresponds to a typical persona profile template (Nielsen et al., 2015), there are variations in persona templates (Guan et al., 2021) which might affect how people process persona information. Future work could thus investigate the number of personas when using alternative persona templates, e.g., those with primarily text content.

Fifth, the notions of primary persona (see, e.g., Aoyama, 2005), secondary persona or other types of personas were not considered in this study. Therefore, we do not know if operationalizing this concept as a variable would affect certain results of the presented study. Future work could investigate this matter by specifically assigning (or asking the persona user to assign) primary and secondary personas for the design task.

Sixth, the task used in the study is not entirely representative of the use of personas in general. This is because the participants were asked to select just one of the personas to use in a design task, rather than to consider or design for the set as a whole (or even for a subset of the personas). While we constrained the task to one persona to make the results more tractable (i.e., analyzing a clear choice made by the persona users), future work could investigate tasks where designers are not limited to choose only one persona.

Seventh, while our research indicates that fifteen is a 'safe number' of personas, more research is needed to establish the upper limit that may form a recommended number of personas. However, we speculate that *the number of personas can be considerably higher than the fifteen used here — even in the hundreds*. This is because efficient filtering and search functions can enhance the users' ability to narrow down and choose personas for a given task. Also, there may be a lower limit to the 'right' number of personas, when decreases in task effectiveness and almost certainly end-user representativeness are considered.

Finally, it is important to clarify if the users of personas consider the number of personas they are presented with as 'too much' to handle, especially when using personas to facilitate communication among team members. Prior literature indicates issues with coordination among development groups when personas become more plentiful. Thus, using a larger number of personas to support coordination between different development groups and teams is an interesting topic for future research.

8. Conclusion

Conventional practice in persona creation favors fewer than ten personas, because this is generally seen to provide a better user experience (*small personas hypothesis*). Yet, interactive persona systems can help users cope with more personas, with possible advantages for inclusive design (*big personas hypothesis*). Based on these two alternative perspectives, we tested two sets of hypotheses – one for each perspective. The results suggest that more personas do not hamper users' recall or their perceptions of the persona, but they do increase the diversity of the end-user representation and user choices. With more personas, users adjust their behaviors to process the persona information more efficiently. Therefore, the 'less than ten' rule of thumb might not be appropriate, especially when using interactive persona systems. Ultimately, our study suggests that having more personas than are conventionally recommended can be helpful for attaining a more diverse understanding of end-users, and thus support inclusive design.

CRediT authorship contribution statement

Joni Salminen: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Soon-gyo Jung:** Software, Resources, Data curation, Visualization. **Lene Nielsen:** Resources, Writing – original draft, Visualization. **Sercan Şengün:** Methodology, Investigation. **Bernard J. Jansen:** Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors have no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijhcs.2022.102915.

References

Aboelmaged, M., Mouakket, S., 2020. Influencing models and determinants in big data analytics research: a bibliometric analysis. Inf. Process. Manag. 57 (4), 102234 https://doi.org/10.1016/j.ipm.2020.102234.

Adamowicz, W., Swait, J., 2013. Are food choices really habitual? Integrating habits, variety seeking and compensatory choice in a utility maximizing framework. Am. J. Agric. Econ. 95 (1), 17–41. https://doi.org/10.1093/ajae/aas078.

Adlin, T., Pruitt, J., 2010. The Essential Persona Lifecycle: Your Guide to Building and Using Personas, 1st ed. Morgan Kaufmann Publishers Inc.

Ali Amer Jid Almahri, F., Bell, D., Arzoky, M, 2019. Personas design for conversational systems in education. Informatics 6 (4), 46. https://doi.org/10.3390/informatics6040046.

Al-Razgan, M.S., Al-Khalifa, H.S., Al-Shahrani, M.D, 2014. Heuristics for evaluating the usability of mobile launchers for elderly people. In: International Conference of Design, User Experience, and Usability, pp. 415–424.

An, J., Kwak, H., Jung, S., Salminen, J., & Jansen, B.J. (2018). Customer segmentation using online platforms: isolating behavioral and demographic segments for persona creation via aggregated user data. *Soc. Netw. Anal. Min.*, 8(1), 54. https://doi.org/10.1007/s13278-018-0531-0.

An, J., Kwak, H., Salminen, J., Jung, S., Jansen, B.J., 2018b. Imaginary people representing real numbers: generating personas from online social media data. ACM Transact. Web (TWEB) 12 (4), 27. https://doi.org/10.1145/3265986.

Antle, A.N., 2006. Child-personas: fact or fiction?. In: Proceedings of the 6th Conference on Designing Interactive Systems, pp. 22–30.

Anvari, F., Richards, D., 2016. A method to identify talented aspiring designers in use of personas with personality. In: Maciaszek, L.A., Filipe, J. (Eds.), Evaluation of Novel Approaches to Software Engineering. Springer International Publishing, pp. 40–61. https://doi.org/10.1007/978-3-319-30243-0_3. Vol. 599.

Anvari, F., Richards, D., 2018. Personas with knowledge and cognitive process: tools for teaching conceptual design. In: Pacific Asia Conference on Information Systems (PACIS 2018, pp. 1178–1191. In: https://researchers.mq.edu.au/en/publications/personas-with-knowledge-and-cognitive-process-tools-for-teaching.

Anvari, F., Richards, D., Hitchens, M., Tran, H.M.T., 2019. Teaching user centered conceptual design using cross-cultural personas and peer reviews for a large cohort of students. In: 2019 IEEE/ACM 41st International Conference on Software Engineering: Software Engineering Education and Training (ICSE-SEET), pp. 62–73. https://doi.org/10.1109/ICSE-SEET.2019.00015.

Aoyama, M., 2005. Persona-and-scenario based requirements engineering for software embedded in digital consumer products. In: Proceedings of the 13th IEEE International Conference on Requirements Engineering (RE'05), pp. 85–94. https://doi.org/10.1109/RE.2005.50.

Berkel, N.van, Dennis, S., Zyphur, M., Li, J., Heathcote, A., Kostakos, V, 2021. Modeling interaction as a complex system. Hum. Comput. Interact. 36 (4), 279–305. https://doi.org/10.1080/07370024.2020.1715221.

Blomquist, A., Arvola, M., 2002. Personas in action: ethnography in an interaction design team. In: Proceedings of the Second Nordic Conference on Human-Computer Interaction, pp. 197–200.

Brickey, J., 2010. System For Persona Ensemble clustering: A cluster Ensemble Approach to Persona Development. University of Colorado at Denver [Doctoral dissertation].

Burnett, M., Stumpf, S., Macbeth, J., Makri, S., Beckwith, L., Kwan, I., Peters, A., Jernigan, W., 2016. GenderMag: a method for evaluating software's gender inclusiveness. Interact. Comput. 28 (6), 760–787.

Canossa, A., Drachen, A., et al., 2009. Play-personas: behaviours and belief systems in user-centred game design. In: Gross, T., Gulliksen, J., Kotzé, P., Oestreicher, L., Palanque, P., Prates, R.O., et al. (Eds.), Human-Computer Interaction – INTERACT 2009. Springer, Berlin Heidelberg, pp. 510–523. https://doi.org/10.1007/978-3-642-03658-3_55 (Vol. 5727.

Clarke, M.F., 2015. The work of mad men that makes the methods of math men work: practically occasioned segment design. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, pp. 3275–3284.

Cleland-Huang, J., 2013. Meet Elaine: a persona-driven approach to exploring architecturally significant requirements. IEEE Softw. 30 (4), 18–21. https://doi.org/10.1109/MS.2013.80.

Cooper, A., 1999. The Inmates Are Running the Asylum: Why High Tech Products Drive Us Crazy and How to Restore the Sanity, 1 edition. Sams - Pearson Education.

Cooper, A., 2004. The Inmates Are Running the Asylum: Why High Tech Products Drive Us Crazy and How to Restore the Sanity, 2nd Edition. Pearson Higher Education.

Cutting, K., Hedenborg, E., 2019. Can personas speak? Biopolitics in design processes. In: Companion Publication of the 2019 on Designing Interactive Systems Conference 2019 Companion, pp. 153–157.

Dow, S., Saponas, T.S., Li, Y., Landay, J.A., 2006. External representations in ubiquitous computing design and the implications for design tools. In: Proceedings of the 6th Conference on Designing Interactive Systems, pp. 241–250.

Duchowski, A.T., 2009. Eye Tracking Methodology: Theory and Practice. Springer.

Feldstein, M., Neal, L., 2006. Designing usable, self-paced e-learning courses: a practical guide. ELearn 2006 (8). https://elearnmag.acm.org/featured.cfm?aid=1165344.

Fuglerud, K.S., Schulz, T., Janson, A.L., Moen, A., 2020. Co-creating persona scenarios with diverse users enriching inclusive design. In: Antona, M., Stephanidis, C. (Eds.), Universal Access in Human-Computer Interaction. Design Approaches and Supporting Technologies. Springer International Publishing, pp. 48–59. https://doi.org/10.1007/978-3-030-49282-3_4.

Goh, C.H., Kulathuramaiyer, N., Zaman, T., 2017. Riding waves of change: a review of personas research landscape based on the three waves of HCI. In: Choudrie, J., Islam, M.S., Wahid, F., Bass, J.M., Priyatma, J.E. (Eds.), Information and Communication Technologies For Development. Springer International Publishing, pp. 605–616. https://doi.org/10.1007/978-3-319-59111-7_49.

Goodman, E., Kuniavsky, M., Moed, A., 2013. Observing the User Experience: A Practitioner's Guide to User Research. Morgan Kaufmann.

Goodman, J., Langdon, P., Clarkson, P.J., 2007. Formats for user data in inclusive design. Universal Access in Human Computer Interaction. Coping with Diversity, pp. 117–126. https://doi.org/10.1007/978-3-540-73279-2_14.

Goodman-Deane, J.A.-L., Bradley, M., Waller, S., Clarkson, P.J., 2021. Developing personas to help designers to understand digital exclusion. Proceedings of the Design Society 1, 1203–1212.

Goodman-Deane, J., Waller, S., Demin, D., González-de-Heredia, A., Bradley, M., Clarkson, J.P., 2018. Evaluating inclusivity using quantitative personas. In: the Proceedings of Design Research Society Conference 2018. https://doi.org/10.21606/drs.2018.400.

Greaney, J., Riordan, M., 2003. The use of statistically derived personas in modelling mobile user populations. In: International Conference on Mobile Human-Computer Interaction, pp. 476–480.

Guan, K.W., Salminen, J., Nielsen, L., Jung, S.-.G., Jansen, B.J., 2021. Information design for personas in four professional domains of user experience design, healthcare, market research, and social media strategy. In: Proceedings of the 54th Hawaii International Conference on System Sciences (HICSS'21). https://doi.org/10.24251/HICSS.2021.540, 10.

Gwizdka, J., Cole, M., 2013. Does interactive search results overview help?: an eye tracking study. In: CHI'13 Extended Abstracts on Human Factors in Computing Systems, pp. 1869–1874.

Helgason, I., Smyth, M., 2020. Ethnographic fictions: research for speculative design. In: Companion Publication of the 2020 ACM Designing Interactive Systems Conference, pp. 203–207.

Hong, B.B., Bohemia, E., Neubauer, R., Santamaria, L., 2018. Designing for users: the global studio. In: DS 93: Proceedings of the 20th International Conference on Engineering and Product Design Education (E&PDE 2018), Dyson School of Engineering. ImperialCollege, London. 6th-7th September 2018, pp. 738–743.

Houben, M., Brankaert, R., Wouters, E., 2020. Stakeholder perspectives on design interventions in dementia care. In: Companion Publication of the 2020 ACM Designing Interactive Systems Conference, pp. 43–47.

Huang, X., Wu, L., Ye, Y., 2019. A review on dimensionality reduction techniques. Int. J. Patt. Recognit. Artifi. Intell. 33 (10), 1950017 https://doi.org/10.1142/S0218001419500174.

Hult, L., Irestig, M., Lundberg, J., 2006. Design perspectives. Hum.–Comput. Interact. 21 (1), 5–48. https://doi.org/10.1207/s15327051hci2101_2.

Idoughi, D., Seffah, A., Kolski, C., 2012. Adding user experience into the interactive service design loop: a persona-based approach. Behav. Inf. Technol. 31 (3), 287–303. https://doi.org/10.1080/0144929X.2011.563799.

Jansen, B.J., Salminen, J., Jung, S., 2020. Data-driven personas for enhanced user understanding: combining empathy with rationality for better insights to analytics. Data Inform. Manage. 4 (1), 1–17. https://doi.org/10.2478/dim-2020-0005.

Jansen, B., Jung, S., Salminen, J., 2021. The effect of hyperparameter selection on the personification of customer population data. Int. J. Electr. Comput. Eng. Res. 1 (2) https://doi.org/10.53375/ijecer.2021.31. Article 2.

Jensen, R.H., Strengers, Y., Kjeldskov, J., Nicholls, L., Skov, M.B., 2018. Designing the desirable smart home: a study of household experiences and energy consumption impacts. In: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18, pp. 1–14. https://doi.org/10.1145/3173574.3173578.

Johnson, A., 2008. Users, use and context: supporting interaction between users and digital archives. In: Craven, L. (Ed.), What Are Archives?, 1st Edition. Routledge, pp. 145–164.

Jung, S., An, J., Kwak, H., Ahmad, M., Nielsen, L., Jansen, B.J., 2017. Persona generation from aggregated social media data. In: Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems, pp. 1748–1755.

Jung, S., Salminen, J., Kwak, H., An, J., Jansen, B.J., 2018a. Automatic persona generation (APG): a rationale and demonstration. In: CHIIR '18: Proceedings of the 2018 Conference on Human Information Interaction & Retrieval, pp. 321–324. https://doi.org/10.1145/3176349.3176893.

Jung, S.-.G., Salminen, J., An, J., Kwak, H., Jansen, B.J., 2018b. Automatically conceptualizing social media analytics data via personas. In: Proceedings of the International AAAI Conference on Web and Social Media (ICWSM 2018), p. 2.

Kaasinen, E., Roto, V., Hakulinen, J., Heimonen, T., Jokinen, J.P.P., Karvonen, H., Keskinen, T., Koskinen, H., Lu, Y., Saariluoma, P., Tokkonen, H., Turunen, M., 2015. Defining user experience goals to guide the design of industrial systems. Behav. Inf. Technol. 34 (10), 976–991. https://doi.org/10.1080/0144929X.2015.1035335.

Kannabiran, G., Hoggan, E., Koefoed Hansen, L., 2020. Somehow they are never horny!. In: Companion Publication of the 2020 ACM Designing Interactive Systems Conference, pp. 131–137.

Kim, B.-.D., Kim, S.-.O., 2001. A new recommender system to combine content-based and collaborative filtering systems. J. Datab. Market. Custom. Strat. Manage. 8 (3), 244–252.

Kim, H.M., Wiggins, J., 2016. A factor analysis approach to persona development using survey data. In: Proceedings of the 2016 Library Assessment Conference, pp. 636–646.

Lee, D.D., Seung, S.H., 1999. Learning the parts of objects by non-negative matrix factorization. Nature 401 (6755), 788–791.

Lee, M., Kwahk, J., Han, S.H., Jeong, D., Park, K., Oh, S., Chae, G., 2020. Developing personas & use cases with user survey data: a study on the millennials' media usage. J. Retail. Consum. Serv. 54, 102051 https://doi.org/10.1016/j.jretconser.2020.102051.

Li, Y., Yuan, X., Che, R., 2021. An investigation of task characteristics and users' evaluation of interaction design in different online health information systems. Inf. Process. Manage. 58 (3), 102476 https://doi.org/10.1016/j.ipm.2020.102476.
Marsden, N., Haag, M., 2016. Stereotypes and politics: reflections on personas. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, pp. 4017–4031.
Marsden, N., Hermann, J., Pröbster, M., 2017a. Developing personas, considering gender: a case study. In: Proceedings of the 29th Australian Conference on Computer-Human Interaction - OZCHI '17, pp. 392–396. https://doi.org/10.1145/3152771.3156143.
Marsden, N., Link, J., Büllesfeld, E., 2015. Geschlechterstereotype in persona-beschreibungen. In: Mensch Und Computer 2015–Proceedings.
Marsden, N., Pröbster, M., Haque, M.E., Hermann, J., 2017b. Cognitive styles and personas: designing for users who are different from me. In: Proceedings of the 29th Australian Conference on Computer-Human Interaction, pp. 452–456.
Matthews, T., Judge, T., Whittaker, S., 2012. How do designers and user experience professionals actually perceive and use personas?. In: *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems - CHI '12*, 1219 https://doi.org/10.1145/2207676.2208573.
McGinn, J.J., Kotamraju, N., 2008. Data-driven persona development. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1521–1524. https://doi.org/10.1145/1357054.1357292.
Miaskiewicz, T., Luxmoore, C., 2017. The use of data-driven personas to facilitate organizational adoption–a case study. Des. J. 20 (3), 357–374.
Mijač, T., Jadrić, M., Ćukušić, M., 2018. The potential and issues in data-driven development of web personas. In: 2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), pp. 1237–1242. https://doi.org/10.23919/MIPRO.2018.8400224.
Mulder, S., Yaar, Z., 2006. The User is Always Right: A Practical Guide to Creating and Using Personas For the Web. New Riders.
Nakayama, M., Wan, Y., 2021. A quick bite and instant gratification: a simulated Yelp experiment on consumer review information foraging behavior. Inf. Process. Manage. 58 (1), 102391 https://doi.org/10.1016/j.ipm.2020.102391.
Negi, S., Mitra, R., 2020. Fixation duration and the learning process: an eye tracking study with subtitled videos. J. Eye Mov. Res. 13 (6) https://doi.org/10.16910/jemr.13.6.1. Article 6.
Nielsen, L., 2013. Personas—User Focused Design, 1st ed. Springer-Verlag.
Nielsen, L., 2019. Personas—User Focused Design, 2nd ed. Springer. 2019 edition.
Nielsen, L., Hansen, K.S., Stage, J., Billestrup, J., 2015. A template for design personas: analysis of 47 persona descriptions from Danish Industries and Organizations. Int. J. Sociotechnol. Knowl. Dev. 7 (1), 45–61. https://doi.org/10.4018/ijskd.2015010104.
Nielsen, L., Storgaard Hansen, K., 2014. Personas is applicable: a study on the use of personas in Denmark. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1665–1674.
Parab, S., Bhalerao, S., 2010. Choosing statistical test. Int. J. Ayurv. Res. 1 (3), 187–191.
Probster, M., Haque, M.E., Marsden, N., 2018. Perceptions of personas: the role of instructions. In: 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), pp. 1–8. https://doi.org/10.1109/ICE.2018.8436339.
Pruitt, J., Adlin, T., 2006. The Persona Lifecycle: Keeping People in Mind Throughout Product Design, 1 edition. Morgan Kaufmann.
Pruitt, J., Grudin, J., 2003. Personas: practice and theory. In: Proceedings of the 2003 Conference on Designing for User Experiences, pp. 1–15. https://doi.org/10.1145/997078.997089.
Raijmakers, B., Gaver, W.W., Bishay, J., 2006. Design documentaries: inspiring design research through documentary film. In: Proceedings of the 6th Conference on Designing Interactive Systems, pp. 229–238.
Revella, Adele., 2015. Buyer Personas: How to Gain Insight Into Your Customer's Expectations, Align Your Marketing Strategies, and Win More Business. Wiley.
Rönkkö, K., Hellman, M., Kilander, B., Dittrich, Y., 2004. Personas is not applicable: local remedies interpreted in a wider context. In: Proceedings of the Eighth Conference on Participatory Design: Artful Integration: Interweaving Media, Materials and Practices - Volume 1, pp. 112–120. https://doi.org/10.1145/1011870.1011884.
Rubegni, E., Landoni, M., Jaccheri, L., 2020. Design for change with and for children: how to design digital storytelling tool to raise stereotypes awareness. In: Proceedings of the 2020 ACM Designing Interactive Systems Conference, pp. 505–518.
Rudin, C., 2019. Stop explaining black box machine learning models for high stakes decisions and use interpretable models instead. Nat. Mach. Intell. 1 (5), 206–215. https://doi.org/10.1038/s42256-019-0048-x.
Salminen, J., Froneman, W., Jung, S., Chowdhury, S., Jansen, B.J., 2020a. The ethics of data-driven personas. In: Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems Extended Abstracts, pp. 1–9. https://doi.org/10.1145/3334480.3382790.
Salminen, J., Guan, K., Jung, S., Chowdhury, S.A., Jansen, B.J., 2020b. A literature review of quantitative persona creation. In: CHI '20: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–14. https://doi.org/10.1145/3313831.3376502.
Salminen, J., Jansen, B.J., An, J., Jung, S., Nielsen, L., Kwak, H., 2018a. Fixation and confusion – investigating eye-tracking participants' exposure to information in personas. In: Proceedings of the ACM SIGIR Conference on Human Information Interaction and Retrieval (CHIIR 2018), pp. 110–119. https://doi.org/10.1145/3176349.3176391.
Salminen, J., Jung, S., An, J., Kwak, H., Jansen, B.J., 2018b. Findings of a user study of automatically generated personas. In: Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18, pp. 1–6. https://doi.org/10.1145/3170427.3188470.
Salminen, J., Jung, S., Chowdhury, S.A., Sengün, S., Jansen, B.J., 2020c. Personas and analytics: a comparative user study of efficiency and effectiveness for a user identification task. In: Proceedings of the ACM Conference of Human Factors in Computing Systems (CHI'20. https://doi.org/10.1145/3313831.3376770.
Salminen, J., Jung, S., Santos, J.M., Kamel, A.M., Jansen, B.J., 2021a. Picturing it!: the effect of image styles on user perceptions of personas. In: Proceedings of ACM Human Factors in Computing Systems (CHI'21, pp. 1–6. https://doi.org/10.1145/3411764.3445360.
Salminen, J., Jung, S.-.G., Chhirang, K., Jansen, B.J., 2021b. Instilling knowledge claims of personas from 346 research articles. In: Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, pp. 1–9. https://doi.org/10.1145/3411763.3451619.
Salminen, J., Kwak, H., Santos, J.M., Jung, S., An, J., & Jansen, B.J. (2018). Persona perception scale: developing and validating an instrument for human-like representations of data. *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*, 1–6. https://doi.org/10.1145/3170427.3188461.
Salminen, J., Santos, J.M., Kwak, H., An, J., Jung, S., Jansen, B.J., 2020d. Persona perception scale: development and exploratory validation of an instrument for evaluating individuals' perceptions of personas. Int. J. Hum. Comput. Stud. 141, 102437 https://doi.org/10.1016/j.ijhcs.2020.102437.
Salminen, J., Sengun, S., Jung, S., Jansen, B.J., 2019. Design issues in automatically generated persona profiles: a qualitative analysis from 38 think-aloud transcripts. In: Proceedings of the ACM SIGIR Conference on Human Information Interaction and Retrieval (CHIIR), pp. 225–229. https://doi.org/10.1145/3295750.3298942.
Sankupellay, M., Niesel, C., Medland, R., Mealy, E., 2015. Motivation and behavioural patterns of students accessing a peer- facilitated support for learning program. In: *Proceedings of the Australisian PASS and Peer Learning Conference*. Australisian PASS and Peer Learning Conference. Melbourne, Australia.
Schäfer, K., Rasche, P., Bröhl, C., Theis, S., Barton, L., Brandl, C., Wille, M., Nitsch, V., Mertens, A., 2019. Survey-based personas for a target-group-specific consideration of elderly end users of information and communication systems in the German health-care sector. Int J Med Inform 132, 103924. https://doi.org/10.1016/j.ijmedinf.2019.07.003.
Sim, G., Shrivastava, A., Horton, M., Agarwal, S., Haasini, P.S., Kondeti, C.S., McKnight, L., 2019. Child-generated personas to aid design across cultures. In: Lamas, D., Loizides, F., Nacke, L., Petrie, H., Winckler, M., Zaphiris, P. (Eds.), Human-Computer Interaction – INTERACT 2019. Springer International Publishing, pp. 112–131. https://doi.org/10.1007/978-3-030-29387-1_7.
Simon, H.A., 1956. Rational choice and the structure of the environment. Psychol. Rev. 63 (2), 129–138. https://doi.org/10.1037/h0042769.
Singh, H., 2020. Improving customer segmentation in E-commerce using predictive neural network. Int. J. Adv. Trend. Comput. Sci. Eng. 9 (2), 2326–2331. https://doi.org/10.30534/ijatcse/2020/215922020.
Song, X., Liu, C., Zhang, Y., 2021. Chinese college students' source selection and use in searching for health-related information online. Inf. Process. Manage. 58 (3), 102489 https://doi.org/10.1016/j.ipm.2021.102489.
Spiliotopoulos, D., Margaris, D., Vassilakis, C., 2020. Data-assisted persona construction using social media data. Big Data Cognit. Comput. 4 (3), 21. https://doi.org/10.3390/bdcc4030021.
Stevenson, P.D., Mattson, C.A., 2019. The personification of big data. Proceed. Des. Soc. 1 (1), 4019–4028. https://doi.org/10.1017/dsi.2019.409.
Theil, A., Buchweitz, L., Fuentes, M., Korn, O., 2020. Co-designing assistive tools to support social interactions by individuals living with deafblindness. In: Companion Publication of the 2020 ACM Designing Interactive Systems Conference, pp. 79–83.
Turner, P., Turner, S., 2011. Is stereotyping inevitable when designing with personas? Des. Stud. 32 (1), 30–44.
Viana, G., Robert, J.-.M., 2016. The practitioners' points of view on the creation and use of personas for user interface design. In: International Conference on Human-Computer Interaction, pp. 233–244.
Wan, Y., Menon, S., Ramaprasad, A., 2003. How it happens: a Conceptual explanation of choice overload in online decision-making by individuals. In: Proceedings of the Ninth Americas Conference on Information Systems (AMCIS), pp. 2379–2384.
Zhang, X., Brown, H.-.F., Shankar, A., 2016. Data-driven personas: constructing archetypal users with clickstreams and user telemetry. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, pp. 5350–5359.
Zhou, Z., Sun, L., Zhang, Y., Liu, X., Gong, Q., 2020. ML lifecycle canvas: designing machine learning-empowered UX with material lifecycle thinking. Hum.–Comput. Interact. 35 (5–6), 362–386. https://doi.org/10.1080/07370024.2020.1736075.
Zhu, H., Wang, H., Carroll, J.M., 2019. Creating persona skeletons from imbalanced datasets—a case study using U.S. older adults' health data. In: Proceedings of the 2019 on Designing Interactive Systems Conference - DIS '19, pp. 61–70. https://doi.org/10.1145/3322276.3322285.