Behaviour & Information Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tbit20

From skeuomorphism to flat design: age-related differences in performance and aesthetic perceptions

Inês Cunha Vaz Pereira Urbano , João Pedro Vieira Guerreiro & Hugo Miguel Aleixo Albuquerque Nicolau

BEHAVIOUR & INFORMATION TECHNOLOGY
https://doi.org/10.1080/0144929X.2020.1814867

From skeuomorphism to flat design: age-related differences in performance and aesthetic perceptions

Inês Cunha Vaz Pereira Urbano[a], João Pedro Vieira Guerreiro [b] and Hugo Miguel Aleixo Albuquerque Nicolau [a]

[a]Department of Computer Science and Engineering, Instituto Superior Técnico, University of Lisbon, Lisbon, Portugal; [b]LASIGE, Faculdade de Ciências, Universidade de Lisboa, Lisbon, Portugal

ABSTRACT

The design of graphical user interfaces has been evolving from skeuomorph interfaces – which use elements that mimic the aesthetics and functionality of their real-world counterparts – to minimalist and flat designs. Despite the growing popularity of these new design approaches, they can be challenging for older adults who experience a decline in visual and cognitive abilities. Still, little is known about user performance, aesthetic perception, and preference of older adults, particularly in comparison to younger users and traditional skeuomorph interfaces. In this paper, we examine the performance and aesthetic perception of older (65–77 years old) and younger (20–40) adults with three design approaches: skeuomorph, skeuominimalist, and flat design. Results show flat design is either slower or less accurate than traditional skeuomorph interfaces for older adults across three tasks: visual search, identifying clickable objects, and multiple page navigation. Younger adults were less susceptible to performance differences between design approaches, but still subject to 'click uncertainty' with flat interfaces. Skeuominimalism did not show clear performance benefits over flat design or skeuomorphism, while the latter reduced the performance gap between age groups. Finally, younger adults preferred the simplicity of skeuominimalism, while older adults preferred skeuomorph interfaces because of the perceived usability, beauty, and trustiness.

ARTICLE HISTORY
Received 5 April 2019
Accepted 16 August 2020

KEYWORDS
Skeuomorph; skeuominimalist; flat; age; performance; aesthetics

1. Introduction

Over the last decade, the design of graphical user interfaces has seen several changes relating to its visual appearance. Skeuomorphism is being increasingly replaced by minimalist user interfaces. Skeuomorph design describes interface objects that mimic their real-world counterparts in how they appear and are used (Norman 1999). Apple's iBooks app (iOS 6) is a great example of a skeuomorph design as virtual books resemble real books and are displayed in a virtual bookshelf. This interface presents familiar concepts and three-dimensional features (e.g. depth, shadows) that enable users to identify interactive objects and understand how to operate them.

However, since the advent of Windows Phone 7 in 2010, flat user interfaces have been widely adopted from mobile to Web interfaces. For example, Apple shifted from skeuomorphism to flat design since iOS 7 (2013). Flat design adopts a minimalist approach where interfaces are stripped down to their barest essentials. Abstract graphic forms replace realistic icons (e.g. the 'hamburger' icon) and bold colours are used to fill spaces. Text is often used with condensed and light variations of typefaces resulting in low density of screen information. This design philosophy emerged as skeuomorph interfaces grew increasingly complex and cluttered. The flat design represents a self-contained two-dimensional digital environment where there is no place for anything replicating three-dimensional objects of the real-world (Banga and Weinhold 2014). Flat interfaces are designed to be perceived as modern and minimalistic without visual distractions that can help users of all ages to focus on what matters the most. After its introduction, flat design was widely criticised by human–computer interaction experts[1,2,3,4] as it ignores the three-dimensional nature of the human brain. For instance, visual cues that reference real-world properties such as texture, lighting, and shadows are removed from flat design, which can render interfaces harder to understand and use (Burmistrov et al. 2015; Creager and Gillan 2016).

Aiming to bridge the gap between skeuomorphism and flat design, in 2014, Google proposed material design, often connected with a skeuominimalist

CONTACT Hugo Miguel Aleixo Albuquerque Nicolau hugo.nicolau@tecnico.ulisboa.pt Instituto Superior Técnico, Room 2-N9.21, Porto Salvo, 2744-016, Portugal

approach (Page 2014). As in flat design, skeuominimalism aspires to minimalist user interfaces; however, it leverages depth effects such as lighting and shadows to provide meaning about interactive elements. Material design is the design approach nowadays used throughout Google's wide array of web and mobile products. It is assumed that this design approach can be a compromise between the unnecessary and overly complex visuals of skeuomorph designs and the lack of affordances of flat interfaces. This is particularly relevant for those who experience decline in perceptual and cognitive abilities associated with age (Cansino et al. 2013; Ishihara et al. 2001; Spear 1993). However, little is known about the user performance and perceived aesthetics of older adults, especially in comparison to younger adults who grew in a digital world.

While previous research has investigated the benefits and costs of different interface designs, it is often restricted to younger adults' performance (Burmistrov et al. 2015; Wu et al. 2015; Creager and Gillan 2016; Zhang, Wang, and Shi 2017). Although previous efforts have been taken to examine the effect of age when using multiple design approaches there are three main limitations: first, most studies only investigate skeuomorph and flat designs, which correspond to both extremes of a continuum of design approaches (Cho et al. 2015; Oswald and Kolb 2014; Backhaus, Trapp, and Thüring 2018). Hybrid approaches, such as skeuominimalist design (e.g. Google's material design), are neglected. Second, studies are usually limited to subjective preference and fail to quantify users' performance (e.g. speed and errors) (Backhaus, Trapp, and Thüring 2018; Robbins 2014). Third, the current body of literature reports mixed findings on how age affects aesthetic perception and user performance of different design approaches(Cho et al. 2015; Oswald and Kolb 2014; Robbins 2014). For instance, while (Cho et al. 2015) shows that the degree of realism of skeuomorphic design is positively correlated with preference, (Robbins 2014) reports that older adults preference was split between skeuomorphic and flat design. On the other hand, (Oswald and Kolb 2014) demonstrate that older adults experience more challenges with skeuomorphic interfaces than flat interfaces. All these limitations suggest the need for a more comprehensive examination of how age affects aesthetic perception and user performance across multiple design approaches.

In this work, we systematically investigate the effect of design using three design approaches: skeuomorph, skeuominimalist, and flat. We report on a study with 20 older and 20 younger adults, comparing user performance and perceived aesthetics. This research is necessary as the world population is ageing (He, Goodkind, and Kowal 2016) and older users are increasingly using technology, particularly the Web (Kohlbacher, Herstatt, and Levsen 2015). Understanding how to create interfaces for this age group is crucial to guarantee an inclusive information society and access to a wide range of services from shopping and transportation to health and communication. The present study aims to work towards inclusive technologies that can cope with the differences that come along with natural aging age (e.g. decline in memory ability, colour perception, and visual acuity) by extending the current body of knowledge on interface design.

The main contribution of this paper is a thorough investigation on how efficiency, effectiveness, and perceived aesthetics are influenced by age group in a continuum of design approaches (i.e. skeuomorph, skeuominimalist, and flat) across three representative tasks of Web usage: visual search, clicking objects, and multiple page navigation. The study has three main goals: first, to examine user performance and perceived aesthetics of older and younger adults; second, to analyse the differences (and similarities) between user interface design approaches and the relationship with age group; and finally, to investigate how user performance varies with type of task.

1.1. Empirical studies on user interface design

Skeuomorphism has been the 'de facto' design approach over the past decades, until 2010 where Windows introduced flat design on its mobile operative system. Since then researchers have been trying to understand how these two design approaches compare against each other. Stickel, Pohl, and Milde (2014) compared a set of native iOS 6 (skeuomorph) and iOS7 (flat) system icons in terms of user preference. They then examined these icons using a qualitative inspection method. Results suggest that the missing information resulting from design simplification can play a major role in lower acceptance rates, leading the authors to conclude that flat design should put more focus on the semantics of interface elements. In another study (Li et al. 2014), flat icons were rated higher on semantic scales such as 'timeless' and 'simplicity', but fared worse than skeuomorph icons on 'identity', 'interest', and 'familiarity'. The authors suggest that both design approaches cannot co-exist or be replaced by each other, therefore designers may be forced to choose between them depending of context or target user group.

Oswald and Kolb (2014) investigated the effects of learnability of both design approaches based on users' subjective impressions, showing a trend to flat designs to become more accepted as 'serious' and 'professional' as users get acquainted with new interaction metaphors. However, the authors warn that these subjective attributions may be disconnected from factual usability performance. Page (Page 2014) studied the role of skeuomorphism and flat design in design education, showing that both approaches are relevant in user interface and could be used to explore other concepts such as skeuominimalism. Wu et al. (Wu et al. 2015) investigated the difference of users' emotion experience between skeuomorphism, flat, and skeuominimalist design in a car navigation interface. The lowest experience rating was given to skeuomorphism and the highest to skeuominimalist design.

Schneidermeier, Hertlein, and Wolff (2014) directly compared Windows 7 (skeuomorph) against Windows 8 (flat) and showed that the older version of the operating system was more usable. Similarly, Burmistrov et al. (2015) showed that flat interfaces require higher cognitive load, more time, and are prone to more errors when compared to their skeuomorph counterpart. The authors strongly suggest not replacing interfaces developed over decades of research with flat designs. Creager and Gillan (2016) studied the effect of shading gradients on the findability and discoverability of user interface elements. Their findings indicate that shading can aid users in search tasks, but its overuse can be considered a distraction. They advocate the use of almost-flat design. Zhang, Wang, and Shi (2017) analysed the emotional cognition of skeuomorphism and flat design icons. Results show that icons with skeuomorphism elements are preferred and load off the trouble users may have in understanding how to use digital products.

More recently, Xi and Wu (2018) investigated user performance in visual search tasks between four icon styles: line, Metro, flat, and skeuomorphism. Users had the highest search efficiency in abstract icons such as line and Metro style icons, second in flat icons, and the lowest in skeuomorphism icons. Spiliotopoulos et al. (Spiliotopoulos, Rigou, and Sirmakessis 2018) examined how users perceive skeuomorphism and flat designs at the level of icon design. Results did not show significant differences in terms of icon recognizability, task completion time or number of errors but (novice and expert) users perceived flat design as more usable. However, when executing web tasks there was a correlation between skeuomorph design and increased experienced difficulty. Moreover, flat design allowed expert users to execute their tasks faster. The authors finish stating that age may be an important factor influencing performance and preference over design approach, as older people that have not been using technology all their life may behave differently. Indeed, all previously reported studies are restricted to younger adults. Even so, results are often contradictory.

1.2. Age-related changes and user interface design

Aging leads to gradual decline in sensory, cognitive, and motor abilities (Ketcham and Stelmach 2001; Ishihara et al. 2001), which affect how older adults perform with computer tasks. Reduced visual perception is a main contributing factor on how older users perceive and interact with technologies, since most user interfaces are highly visual. Older users may face greater difficulties at locating targets on screen and perceiving changes due to reduced visual acuity, which can also affect reaction and task completion times (Bobeth et al. 2012; Czaja and Lee 2009). Decline in tactile spatial acuity can also affect computer tasks that require orientation and hand dexterity (Stössel 2009; Huppert 2003). Similarly, reduced cognitive functions may also have an influence on computer navigation and retrieval tasks (Crabb and Hanson 2016). It is important to notice that although in HCI research an age threshold is typically used (often 65) to classify a user as an 'older' adult, age alone does not define this group. Rather it is defined by its common characteristics that may vary by context and individuals' life experiences (Vines et al. 2015). Giving this set of characteristics, it can be difficult to isolate which specific factors contribute to differences in performance.

Research has shown age-related differences in pointing (Rogers et al. 2005; Cabreira and Hwang 2018), web browsing (Hanson and Crayne 2005), and touch performance (Findlater et al. 2013). It was also observed that increased physiological tremor is negatively correlated with text-entry performance (Nicolau and Jorge 2012). However, few studies have examined the effect of interface design approach on user performance and aesthetic perception for older adults.

Cho et al. (Cho et al. 2015) explored the value of skeuomorphism as an icon style for older people with ages ranging from 65 to 90 years. They concluded that the degree of realism is positively correlated with both preference and understandability. Robbins (Robbins 2014) examined icon preference for skeuomorphism and flat design in three age groups (younger: 13–16, middle: 27–45, older: 46+). While the author found that middle age participants prefer flat designs, both the younger and older adults were split on the two design approaches. More recently, Oswald (Oswald 2018) conducted a comparative usability study between flat design and skeuomorphism. There was no clear conclusion as both design approaches demonstrated advantages and disadvantages; however, older and novice users experienced more challenges using skeuomorph interfaces than flat interfaces. Backhaus, Trapp, and Thüring (2018) also compared the usability of skeuomorph and flat interfaces with a cohort of 24 participants split between younger and older users. Participants were considered 'young' if they had used a personal computer regularly before the age of eighteen ('digital natives' (Prensky 2001)), and older otherwise ('digital immigrants'). Older participants showed a preference for skeuomorph designs whereas younger adults favoured flat design. The younger group rated visual aesthetics, status, and positive emotions higher for the flat design compared to the older group.

These mixed findings suggest a need for more comprehensive examination of how age affects aesthetic perception of different design approaches. Moreover, few studies have compared design approaches beyond qualitative measures and subjective preference. Despite the growing popularity of flat and skeuominimalist interfaces, little is known about the objective performance benefits/drawbacks and aesthetic perception of these design styles for older adults, especially in comparison to younger adults and traditional skeuomorph interfaces.

2. Method

The goal of this study was to examine age-related differences on user performance and aesthetic perception with skeuomorph, skeuominimalist, and flat interfaces.

2.1. Research Questions

The study aims to answer four main research questions:

1. *What is the overall user performance difference – in terms of speed and accuracy – among skeuomorph, skeuominimalist, and flat interfaces?*
2. *What is the user performance difference within different types of tasks – visual search, clicking objects, and multiple page navigation – among skeuomorph, skeuominimalist, and flat interfaces?*
3. *What is the user performance difference between older and younger adults when using each of the design approaches?*
4. *What is the aesthetic perception and preference of older and younger adults?*

2.2. Participants

We recruited 20 adults aged 20–40 ($M = 24.6$, SD = 5.2) and 20 adults aged 65–77 ($M = 70$, SD = 4.3). The younger (Table 1) and older (Table 2) groups contained 8 and 15 female participants, respectively. All younger participants used computer and mobile devices on a daily basis. Regarding older adults, all but 4 participants reported daily mobile use. The majority of older adults also reported regular computer use (9 daily and 5 at least once a week). Only one participant had never used a computer or mobile device, but received short training on how to interact with the computer using a mouse. We recruited younger participants from a local University using word of mouth and snowball sampling. Older participants were recruited from a local Senior University using a similar approach. Participation was voluntary and no compensation or incentives were given. None of the participants had severe visual or

Table 1. Demographic information and technology experience and use of the younger participants group.

Part.	Age	Gender	Tech Experience (yrs)	Computer Use	Mobile Device Use
Y1	22	F	11	daily	daily
Y2	20	F	6	daily	daily
Y3	20	F	13	daily	daily
Y4	22	M	8	daily	daily
Y5	23	F	10	daily	daily
Y6	24	M	10	daily	daily
Y7	24	M	10	daily	daily
Y8	22	M	13	daily	daily
Y9	23	M	12	daily	daily
Y10	23	M	13	daily	daily
Y11	21	F	11	daily	daily
Y12	21	F	10	daily	daily
Y13	29	F	18	daily	daily
Y14	20	M	13	daily	daily
Y15	21	M	11	daily	daily
Y16	22	M	14	daily	daily
Y17	32	M	18	daily	daily
Y18	30	M	16	daily	daily
Y19	33	M	19	daily	daily
Y20	40	F	25	daily	daily

Table 2. Demographic information and technology experience and use of the older participants group.

Part.	Age	Gender	Tech Experience (yrs)	Computer Use	Mobile Device Use
O1	64	F	20	daily	daily
O2	64	F	20	daily	daily
O3	73	F	1	never	daily
O4	74	M	10	never	daily
O5	66	F	5	monthly	daily
O6	77	M	6	monthly	daily
O7	69	F	35	daily	daily
O8	66	M	26	daily	daily
O9	75	F	0	never	never
O10	67	F	15	> monthly	daily
O11	73	F	20	daily	never
O12	65	F	10	> weekly	daily
O13	75	F	20	daily	daily
O14	71	F	10	daily	never
O15	67	M	34	daily	daily
O16	73	F	20	daily	never
O17	66	F	7	monthly	daily
O18	77	M	8	> weekly	daily
O19	71	F	4	> weekly	daily
O20	67	F	18	> weekly	daily

motor impairments. They were all able to see the screen content and operate a mouse device.

2.3. Apparatus

The experimental testbed was built in HTML5, CSS, and Javascript. It ran on a laptop computer (Asus VivoBook S4) in the Chrome browser. The laptop had a 14-inch display, was set to a resolution of 1920 × 1080, and was wirelessly connected to Logitech M235 optical mouse. All participants' actions were logged for analysis purposes.

2.4. Tasks

We investigated user performance across three types of tasks:

(1) Visual search – a search for an icon depicting a specific object (e.g. 'calculator' – see Table 3) in a matrix of 4 × 4 icons presented on the screen. The position of the target icon was randomly distributed between the 16 possible positions of the matrix. Participants were instructed to click the icon that corresponded to the target object.

(2) Clicking objects – 'click uncertainty' is often pointed as one of the drawbacks of flat design as interactive elements are not easily understandable making an interface harder to use. In this task, participants were instructed to click all screen objects that look clickable (buttons, menus, images, links, etc. – Table 4) in a web page (See one example in Figure 1). For each webpage, we designed 3 versions that corresponded to the 3 design conditions (skeuomorph, skeuominimalist, flat) of the study. Moreover, as participants were exposed to all design conditions, and to mitigate learning effects, for each version we create 3 alternatives of similar complexity (i.e. same number and type of clickable objects). The main difference between webpages was the content/

Table 3. Icons used in the experiment.

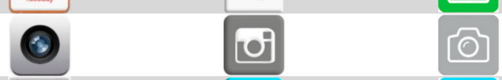
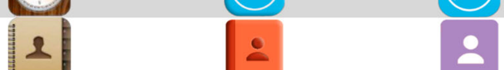
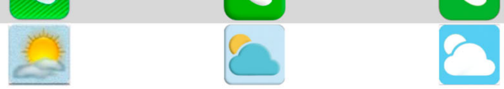
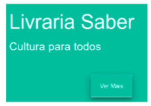
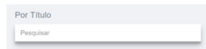
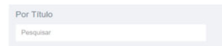
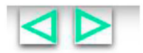
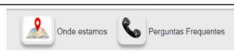
Icon	Skeuomorph	Skeuominimalist	Flat
Book			
Calculator			
Calendar			
Camera			
Clock			
Chef			
Compass			
Contacts			
Games			
Messages			
Microphone			
Movies			
Notes			
Settings			
Phone			
Weather			

Table 4. Example of elements of 'Clicking Objects' task for all three designs.

Elements	Skeuomorph	Skeuominimalist	Flat
Buttons			
Search bars			
Arrows			
Images			
Icons			
News			

theme (books, food, baby clothes). For instance, if a participant was exposed to the books-related webpage in the skeuominimalist conditions, s/he would not experience the same webpage in the following design conditions.

(3) Multiple page navigation – Participants were invited to complete a multi-step task that require them to navigate through 3 web pages and select multiple interface elements. Similarly to the clicking objects task, in order to mitigate learning effects, we built 3 interfaces of similar complexity for each design condition, i.e. we guaranteed that participants could complete the task with the same number of clicks ($N = 5$). Also, button sizes were the same and interactive elements were placed in similar positions. However, the content of each website was different for each task. The navigation tasks were: 'buy 2 pacifiers and let us know the opening hours of the store', 'place an order for the book' – 'O Principezinho' – and print the list of suggested readings', and 'order 2 shrimp and vegetables dishes and check the phone number of the restaurant' (Figure 2). The task ended when participants performed the last required mouse click. Overall, we designed 3 versions of each website (one for each design approach) resulting in 9 different websites.

The icons – shown in Table 3 – were derived from existing icons. We tried to keep a consistent set of graphics within each design type, manipulating some of the icons – in their colour and contrast, shadows and layer effects (using Adobe Photoshop).

3. Procedure

The procedure fit in a single session: while we did not impose duration limits, each session took approximately 20 min for younger adults and up to 40 min for older adults. At the beginning, participants were informed that the overall purpose of the study was to investigate how user performance is affected by interface design. Participants then used the laptop computer to complete a background survey, which included demographic data and technology experience. Next, they used the computer with a randomly assigned design approach (skeuomorph, skeuominimalist, flat) with the three tasks (visual search, clicking objects, multiple page navigation) in a randomised order within each design condition.

For each task, instructions were presented on screen in text. Participants were invited to clarify all doubts before selecting the 'next' button to start the tasks. They were instructed to complete the task as fast and accurately as possible. The instructions remained visible on the top of the screen during the execution of tasks.

At the end of the study, participants were invited to fill a debriefing survey about aesthetic perceptions and overall preference. They were presented with design examples (as shown in Table 3) to differentiate the types of interface design. We presented the whole set of icons so that the difference in design type would become clear and to reduce the influence of preference/dislike for a specific icon of one design.

3.1. Dependent measures

The performance was measured using *time* to complete task and number of *errors*. In addition, we used semantic differential scales to measure aesthetic perception for each design approach. These scales are widely used in the literature – *e.g.* Nagamachi (2011) suggests that every artefacts can be described in a vector space defined by semantic

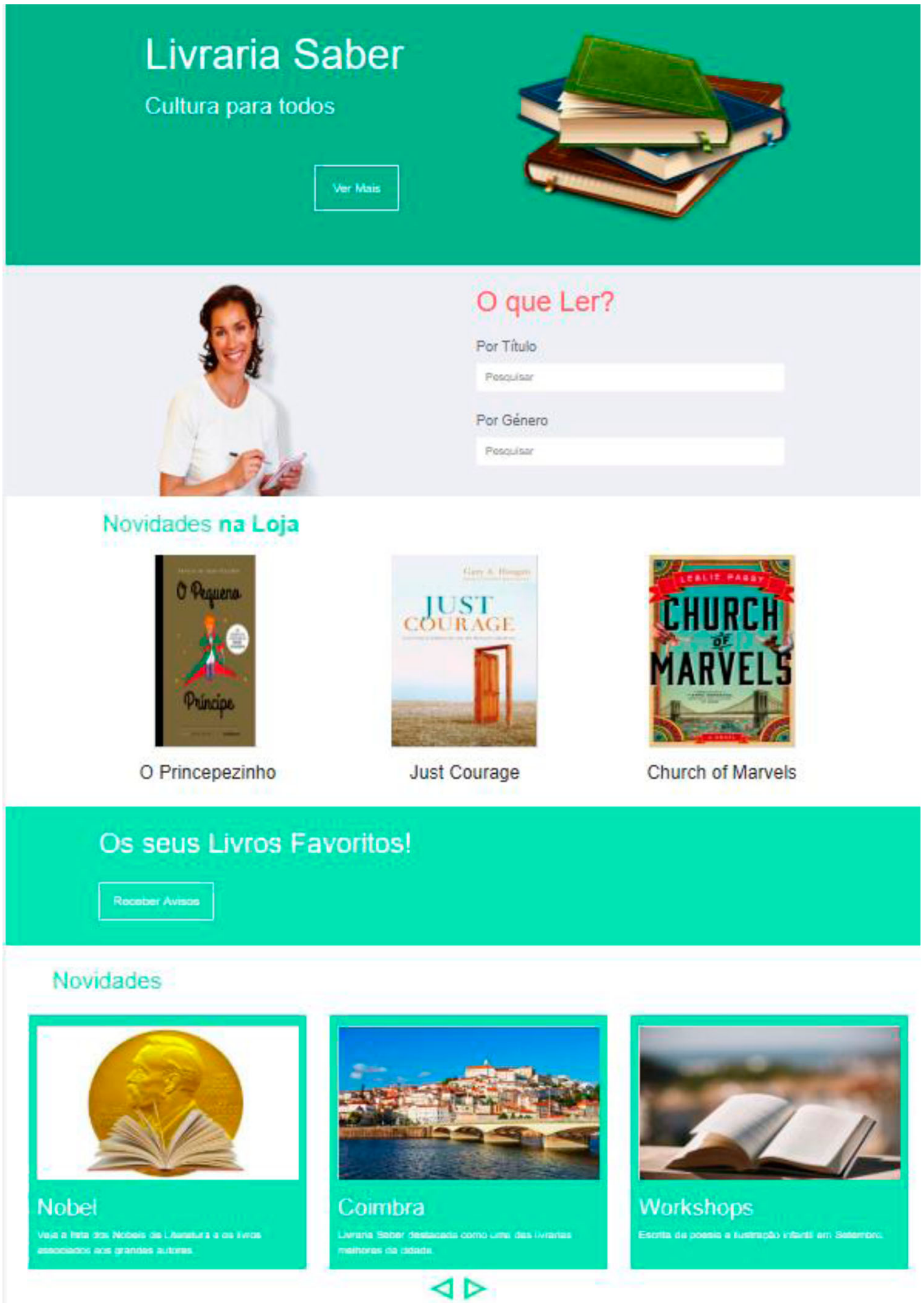


Figure 1. Example of screen displayed to users in 'clicking objects' task in the flat design condition.

words; and Wu et al. (2015) used them when comparing skeuomorph and flat designs. We measured 8 pairs of adjectives ('complex-simple', 'rough-fine', 'traditional-modern', 'boring-interesting', 'ugly-beautiful', 'unreliable-trustworthy', 'hard-easy', and 'slow-fast') that were evaluated on a 7-point scale where '4' served as a neutral response. Participant preference regarding each design approach was also gathered at the end of the session.

3.2. Design and analysis

We used a within-subjects design where each participant experienced all conditions. For each design condition, each participant performed three tasks, resulting in a total of 9 trials per participant. We also had a between-subjects factor, which was age group: older and younger adults. In summary, the study design was: 20 participants × 2 age groups × 3 designs × 3 tasks.

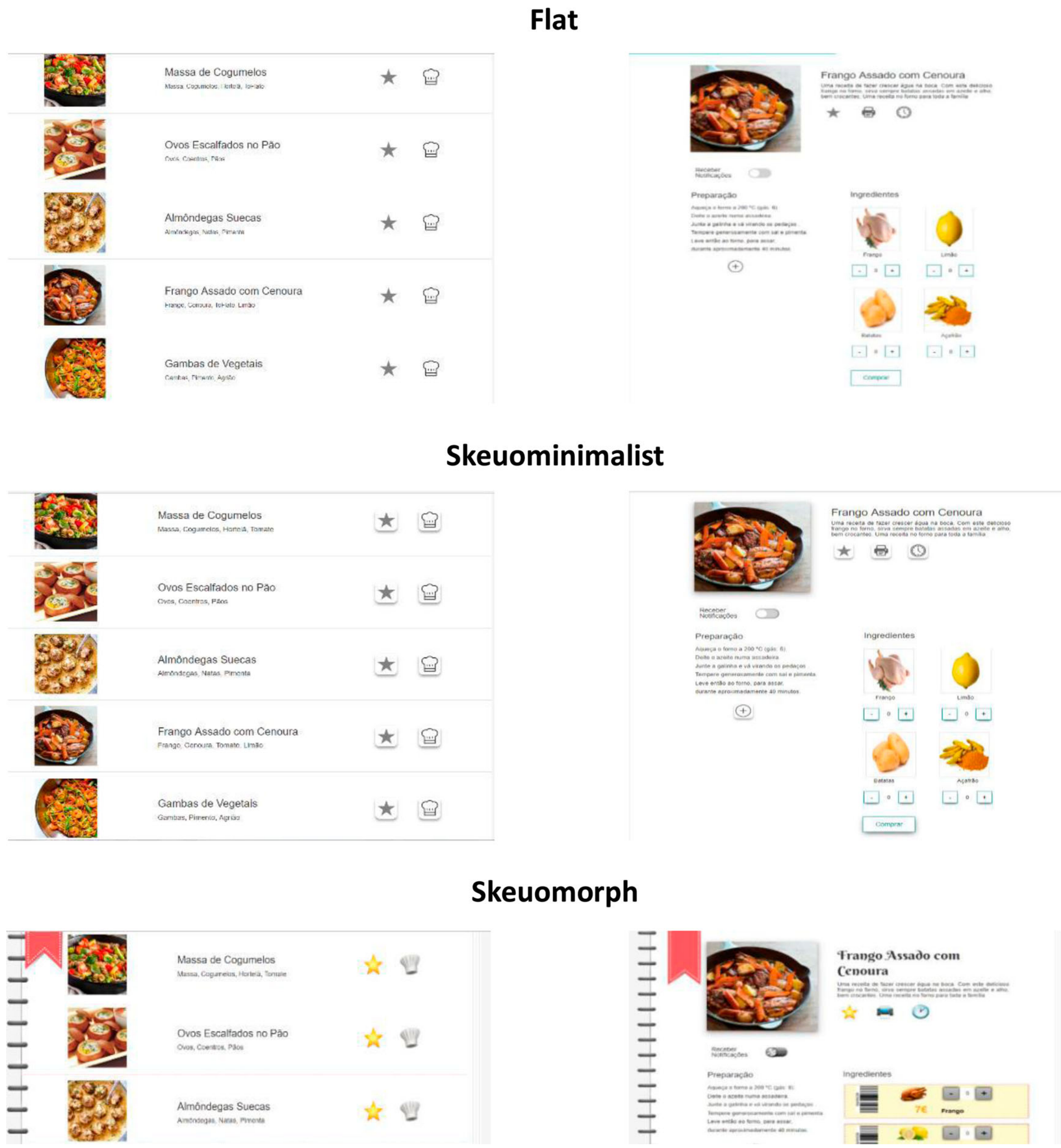


Figure 2. Main and Secondary pages in the 'multiple page navigation' task for the three designs, in the 'recipe' scenario.

We ran a 2-way mixed ANOVA with age group (2 levels) and design condition (3 levels) as the between and within factors, respectively. Observed values were tested for normal distributions (Shapiro-Wilk's test) and homogeneity (Levene's test). In case data failed any of these assumptions, we applied a data transformation (e.g. log, square root) to guarantee that the data fit the mixed ANOVA assumptions. In such case, the appropriate transformation was applied on all samples of the measure being analysed. We also tested for homogeneity of covariances. When we did not have homogeneity of covariances we separated the analysis into individual repeated measures ANOVAs for each age group. Finally, we tested for sphericity (Mauchly's test) and used the Greenhouse-Geisser correction when the assumption was not met.

Perceived aesthetics were measured through 8 semantic differential scales. As ordinal measures rule out parametric analysis, we used the nonparametric Aligned Rank Transform procedure (Wobbrock et al. 2011; Higgins and Tashtoush 1994; Salter and Fawcett 1993), which enables the use of ANOVA after alignment and ranking of data, maintaining the integrity of interaction effects. Although we can analyse both main effects and interaction effects on the transformed data, cross-factor pairwise comparisons cannot be safely conducted. Thus, we used either nonparametric Mann–Whitney U tests or Wilcoxon signed-rank tests on the original data for between- or within-subjects analysis, respectively. Bonferroni corrections were used for the post-hoc comparisons.

Correlations between technology experience (years using technology and experience with computers and tablets) and user performance in all tasks were measured using the Pearson or Spearman correlation methods depending on the normality of the variables.

4. Results

Our goal is to understand users' age-related differences in performance and aesthetic perceptions when using interfaces built following three different design approaches: skeuomorph, skeuominimalist, and flat design. We analyse user performance across three different tasks (i.e. visual search, clicking objects, and multiple page navigation) in terms of speed and error rate. We focus on understanding whether there are differences between age groups and design approaches as well as interactions between these two factors.

4.1. Visual search

In the visual search task, participants had to search for an icon depicting a specific object and select it.

Older adults are slower with flat design. Completion time results are shown in Figure 3. There was a statistically significant interaction between *age group* and *design* on completion time, $F(1.435, 54.514) = 4.643$, $p < .05$, partial $\eta^2 = .109$. Data are mean ± confidence ($\alpha = .05$), unless otherwise stated. Completion time was statistically significantly greater for *flat* design (22.3 ± 1.2s, $p < .05$) compared to *skeuomorph* design in the older adults' group. We did not find statistically significant differences between *skeuominimalist* (15.2 ± 3.5 s) and both *skeuomorph* (11.3 ± 2.3 s, $p = .197$) and *flat* (22.3 ± 1.2s, $p = .241$) designs. Completion time in the younger adults' group was not statistically different across design approaches, $F(2, 38) = 1.975$, $p = .153$, partial $\eta^2 = .094$.

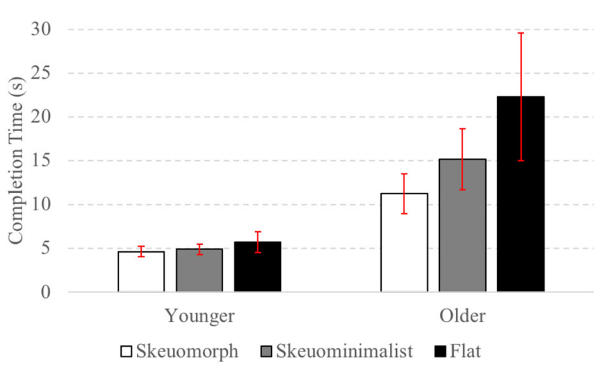


Figure 3. Completion time in visual search task across all design approaches and age groups. Lower is better. Error bars denote 95% confidence intervals.

Table 5. Mean error rates of both younger and older adults in the 'visual search' task for each of the design conditions.

	Skeuomorph	Skeuominimalist	Flat
Younger Adults	6 ± 6%	1 ± 2.6%	12 ± 8.6%
Older Adults	14 ± 9.6%	27 ± 12.7%	31 ± 15.5%

Design does not influence error rate in visual search. Error rate indicates percentage of selections of incorrect icons. There was no statistically significant interaction between factors, $F(2, 76) = 1.897$, $p = .157$, partial $\eta^2 = .048$. However, the main effect of *age group* showed a statistically significant difference in mean error rate between younger and older adults, $F(1, 38) = 13.362$, $p < .001$, partial $\eta^2 = .26$. Mean error rates (see Table 5) experienced by *older* adults were statistically significantly greater compared with *younger* adults. Regarding *design*, we did not find a statistically significant main effect in mean error rate between *design* approaches, $F(2, 76) = 5.126$, $p = .051$, partial $\eta^2 = .076$.

4.2. Clicking objects

In this task, participants were exposed to a webpage and were invited to select all screen objects that looked clickable. Errors correspond to objects that were clickable but not selected by participants or objects that were selected but were not clickable.

Younger adults are generally faster. There was no statistically significant interaction in completion time between factors on completion time, $F(2, 76) = 2.827$, $p = .065$, partial $\eta^2 = .069$, nor as a main effect between *design* approaches, $F(2, 76) = 1.617$, $p = .205$, partial $\eta^2 = .041$. The main effect of *age group* showed a statistically significant difference in mean completion time between user groups, $F(1, 38) = 89.406$, $p < .0005$, $\eta^2 = .702$ (see Table 6 for completion times).

Greater click uncertainty with flat design. Figure 4 shows mean error rates for each factor. There was no statistically significant interaction between *age group* and *design* condition on error rate, $F(1.69, 64.235) = 2.609$, $p = .08$, $\eta^2 = .064$. Unlike mean completion time, the main effect of *design* showed a statistically significant difference in mean error rate between different design approaches, $F(1.69, 64.235) = 9.983$, $p < .0005$, $\eta^2 = .208$. Namely, we found statistically significant differences

Table 6. Mean completion times ± standard deviation (in seconds) of both younger and older adults in the 'clicking objects' task for each of the design conditions.

	Skeuomorph	Skeuominimalist	Flat
Younger Adults	34 ± 4.8s	27 ± 3s	28 ± 3.6s
Older Adults	119 ± 25s	133 ± 31.9s	121 ± 30.7s

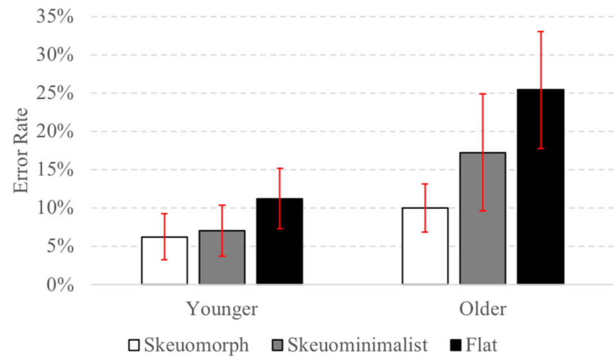


Figure 4. Error rate in clicking objects task across all design approaches and age groups. Lower is better. Error bars denote 95% confidence intervals.

between *skeuomorphism* (younger = 6 ± 3%, older = 10 ± 3.2%) and *flat* designs (younger = 11 ± 4%, older = 25 ± 7.7%, $p < .0005$). However, there were no statistically significant differences between *skeuominimalist* (younger = 7 ± 3.3%, older = 17 ± 7.7%) and both *skeuomorph* ($p = .155$) and *flat* designs ($p = .093$).

4.3. Multiple page navigation

In this task, participants were instructed to complete a composite task that consisted of multiple steps and navigating through 3 web pages to reach the goal. Deviations from the optimal navigation path were considered errors.

Design has no effect on speed in composite tasks. There was no statistically significant interaction between factors, $F(2, 76) = 2.995$, $p = .056$, partial $\eta^2 = .073$. Nevertheless, the main effect of *age group* showed a statistically significant difference in mean completion time between *younger* and *older* adults, $F(1, 38) = 100.502$, $p < .0005$, partial $\eta^2 = .726$. Mean completion times are illustrated in Figure 5. As with previous task types, *older* adults (*skeuomorph* = 100 ± 24.4s, *skeuominimalist* = 101 ± 25.6s, *flat* = 133 ± 41.4s) were statistically significantly slower than *younger* adults (*skeuomorph* = 36 ± 6.1s, *skeuominimalist* = 28 ± 4s, *flat* = 29 ± 6.1s). Regarding *design*, we did not find a statistically significant main effect in mean error rate between *design* approaches, $F(2, 76) = .955$, $p = .389$, partial $\eta^2 = .025$.

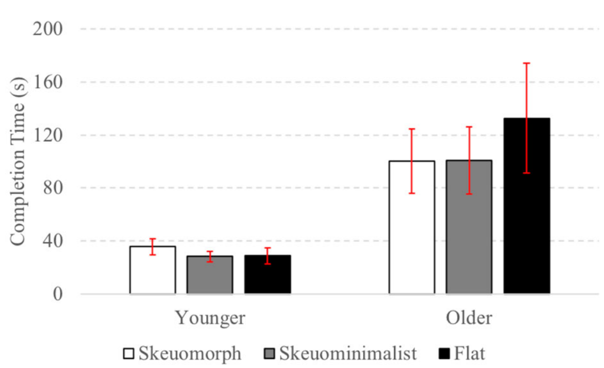


Figure 5. Completion time in multiple page navigation across all design approaches and age groups. Lower is better. Error bars denote 95% confidence intervals.

Table 7. Mean error rates of both younger and older adults in the 'multiple page navigation' task for each of the design conditions.

	Skeuomorph	Skeuominimalist	Flat
Younger Adults	9 ± 5.1%	3 ± 3.1%	6 ± 4.7%
Older Adults	13 ± 6.9%	20 ± 9.9%	35 ± 9.8%

Flat design promotes more errors for older adults. There was a statistically significant interaction between *age group* and *design* on error rate, $F(2, 76) = 8.357$, $p < .005$, partial $\eta^2 = .18$. Error rate (see Table 7) was statistically significantly greater for *flat* design ($p < .005$) compared to *skeuomorph* design in the *older* adults' group. We did not find statistically significant differences between *skeuominimalist* and both *skeuomorph* ($p = .391$) and *flat* ($p = .097$) designs. Error rate in the *younger* adults' group was not statistically different across *design* approaches, $F(2, 38) = 2.326$, $p = .111$, partial $\eta^2 = .109$. These results suggest that 'click uncertainty' is diluted in goal-oriented tasks.

4.4. Perceived aesthetics

Perceived aesthetics were measured through eight 7-point semantic differential scales (Table 8): 'complex-

Table 8. Perceived aesthetics across all differential scales.

		Median [Inter Quartile Range]	
		Younger	Older
Simple-Complex	Skeuomorph	5 [1.25]	4 [.25]
	Skeuominimalist	3 [1.25]	3 [2]
	Flat	2 [1.25]	2 [.25]
Rough-Fine	Skeuomorph	3 [2]	3 [1.25]
	Skeuominimalist	7 [1]	6 [.25]
	Flat	7 [1]	6 [1.25]
Traditional-Modern	Skeuomorph	5 [4.25]	5 [3]
	Skeuominimalist	6 [1]	5 [2.25]
	Flat	6 [3]	5 [4.25]
Boring-Interesting	Skeuomorph	5 [2]	7 [.25]
	Skeuominimalist	6 [2]	6 [1.25]
	Flat	6 [2]	6 [3.25]
Ugly-Beautiful	Skeuomorph	4 [2]	7 [1.25]
	Skeuominimalist	6 [1.25]	6 [1]
	Flat	6 [1.25]	6 [1.75]
Unreliable-Trustworthy	Skeuomorph	5 [3]	7 [0]
	Skeuominimalist	6 [1]	7 [1]
	Flat	7 [1]	7 [1]
Hard-Easy	Skeuomorph	5 [2.25]	7 [0]
	Skeuominimalist	6 [1.25]	6 [.25]
	Flat	6 [2]	5 [1.5]
Slow-Fast	Skeuomorph	5 [2.25]	7 [0]
	Skeuominimalist	6 [1]	6 [.25]
	Flat	6 [1.25]	5 [2.5]

simple', 'rough-fine', 'traditional-modern', 'boring-interesting', 'ugly-beautiful', 'unreliable- trustworthy', 'hard-easy', and 'slow-fast'.

Skeuomorphism is a complex design for younger adults. There was a statistically significant interaction between *age group* and *design* on simple–complex differential semantic scale, $F(1.702, 64.666) = 11.044$, $p < .0005$, partial $\eta^2 = .225$. Data are median [Interquartile Range] unless otherwise stated. *Younger* adults perceived *skeuomorph* design significantly more complex (5 [1.25]) compared to *older* adults (4 [0.25], U = 90.5, Z = −3.068, $p < .005$), which had a neutral rating. Perceived complexity of *skeuomorph* design was greater than both *skeuominimalist* ($p < .0005$, younger = 3 [1.25], older = 3 [2]) and *flat* ($p < .0005$, younger = 2 [1.25], older = 2 [0.25]) designs; however, there was no statistically significant differences between *age groups* ($p > .05$) for these two design approaches.

Skeuomorph UIs are rougher. There was a statistically significant interaction between factors on rough-fine differential semantic scale, $F(1.11, 42.166) = 5.930$, $p < .05$, partial $\eta^2 = .135$. *Younger* adults (7 [1]) perceived *skeuominimalist* interfaces as finer than *older* adults (6 [0.25]). No other statistically significant differences between *age groups* were found. However, there was a statistically significant main effect of *design*, $F(1.276, 48.48) = 127.843$, $p < .0005$, partial $\eta^2 = .771$. Particularly, *skeuomorph* design (younger = 3 [2], older = 3 [1.25]) was rated as rougher than both *skeuominimalist* ($p < .0005$, younger = 7 [1], older = 6 [0.25]) and *flat* design ($p < .0005$, younger = 6 [1], older = 6 [1.25]).

Skeuomorphism is interesting and beautiful (only for older adults). There was a statistically significant interaction between *age group* and *design* on boring-interesting differential semantic scale, $F(1.566, 59.501) = 14.284$, $p < .0005$, partial $\eta^2 = .273$. *Older* adults perceived *skeuomorph* design (7 [0.25]) significantly more interesting than *younger* adults (5 [2], U = 53.5, Z = −4.128, $p < .0005$). We found similar results for the ugly-beautiful semantic scale with a statistically significant interaction between factors, $F(1.669, 63.429) = 11.885$, $p < .0005$, partial $\eta^2 = .238$. *Older* adults rated *skeuomorph* interfaces with a median of 7 [1.25] out of 8 points while *younger* adults had a more neutral view (4 [2], U = 59, Z = −3.996, $p < .0005$). There were no statistically significant differences between *age* groups in the remaining *design* conditions on both boring-interesting and ugly-beautiful scales with median rates of 6 points across conditions.

Flat is perceived as modern as skeuomorph. Although flat and *skeuominimalist* interfaces are usually associated with modern designs, we did not find statistically significant main effects of *age* or *design* nor an interaction between factors in the traditional-modern semantic scale. Younger adults obtained a median of 5 [4.25], 6 [1], and 6 [3] points in *skeuomorph*, *skeuominimalist*, and *flat* design, respectively. Older adults rated *skeuomorphism* with a median of 4 [3] points, *skeuominimalist* with 5 [2.25] points and *flat* with 5 [4.25] points.

Skeuomorph design is perceived as less trustworthy by younger adults. We found a statistically significant interaction between factors on unreliable-trustworthy differential semantic scale, $F(2, 76) = 27.292$, $p < .0005$, partial $\eta^2 = .418$. *Skeuomorph* was perceived as significantly more trustworthy by *older* adults (7 [0]) compared to younger adults (5 [3], U = 34.5, Z = −4.926, $p < .0005$). There were no further age-related differences in both *skeuominimalist* (younger = 6[1], older = 7[1], U = 163, Z = −1.117, $p = .327$) and *flat* designs (younger = 7[1], older = 7[1], U = 194, Z = −.182, $p = .883$).

Opposing views on ease of use. There was a statistically significant interaction between *age group* and *design* on hard-easy differential semantic scale, $F(1.659, 63.052) = 19.624$, $p < .0005$, partial $\eta^2 = .341$. Overall, both user groups rated design conditions positively, i.e. greater than 4 points. *Older* adults perceived *skeuomorph* design significantly easier to use (7 [0]) compared to *younger* adults (5 [2.25], U = 50.5, Z = −4.44, $p < .0005$), while *flat* design (younger = 6[2], older = 5[1.5]) was perceived as significantly harder (U = 114, Z = −2.420, $p < .05$). We did not find statistically significant differences between *age groups* with *skeuominimalist* design.

Skeuomorph design was perceived as faster by older adults. Similarly to hard-easy scale, there was a statistically significant interaction between factors on slow-fast differential semantic scale, $F(2, 76) = 19.553$, $p < .0005$, partial $\eta^2 = .34$. There were statistically significant differences in speed perception between *younger* (5 [2.25]) and *older* adults (7 [0]) with *skeuomorph* interfaces (U = 22.5, Z = −5.109, $p < .0005$). Overall, we found statistically significant differences between all design conditions for *older* adults with *skeuomorphism* being considered the fastest, followed by *skeuominimalist* (6 [0.25], Z = −2982, $p < .01$), and *flat* designs (5 [2.5], Z = −3.308, $p < .005$). Regarding *younger* adults, significant differences were only observed between *skeuomorph* and *skeuominimalist* (6 [1], Z = −2.447, $p < .05$) designs.

4.5. Subjective preference

At the end of the experiment, participants were inquired about their preferred design approach. While none of the younger participants chose the *skeuomorph* design, fifteen (75%) older adults preferred the *skeuomorph* interfaces. A 95% adjusted-Wald binomial CI ranging from 52.8% to 89.2%, shows a lower limit above the three-choice change expectation of 33.3%. Interestingly, none of the older participants had a preference for *skeuominimalist* design. On the other hand, thirteen (65%) younger adults choose *skeuominimalist* design as their preferred condition, which also shows a lower limit above the three-choice change expectation (43.2% to 82%).

5. Discussion

In this section, we answer the research questions proposed at the beginning of this study and limitations of our work.

5.1. Answering the research questions

1. What is the overall user performance difference – in terms of speed and accuracy – among skeuomorph, skeuominimalist, and flat interfaces?

Overall, participants were slower and less accurate with flat design compared with skeuomorph design. Such difference was more noticeable with older participants. For instance, older adults took on average nearly twice as much time completing visual search tasks with flat design compared with skeuomorph design. Regarding error rates, older adults experienced an increase of more than two-fold for all types of tasks. On the other hand, younger participants were less susceptible to speed differences between designs, but flat design was on average less accurate than skeuomorphism. Particularly, younger participants also experienced 'click uncertainty' with flat interfaces, resulting in an 80% increase of error rates when trying to select all clickable elements on a flat interface compared to skeuomorph. These findings extend previous work limited to younger adults showing similar performance decrease (Burmistrov et al. 2015).

In addition, we did not find statistically significant differences between skeuominimalist design and the remaining design approaches for all types of tasks and both user groups. Although skeuominimalist design is highly inspired by minimalistic and flat interfaces it contains some 3D features (shadows and lightning) that give meaning to interactive elements (Creager and Gillan 2016). We did not find skeuominimalist interfaces to be statistically easier or faster to use than flat interfaces across three types of tasks, suggesting it does not comprise all the advantages of skeuomorph design.

Design Implication 1 – Use skeuomorphic design for an overall faster and easier experience: results show that, across multiple tasks, on average both age groups were faster and less erroneous with skeuomorphic interfaces. This is especially visible for older adults.

2. What is the user performance difference within different types of tasks – visual search, clicking objects, and multiple page navigation – among skeuomorph, skeuominimalist, and flat interfaces?

Visual search tasks were slower with flat design for both user groups, although there was no significant difference in error rates. These results suggest that participants can eventually find the intended interface elements but require on average 24% (younger adults) and 98% (older adults) more time than with skeuomorph design. On the clicking objects task, both user groups were susceptible to the 'click uncertainty' phenomenon with flat design where participants are unsure whether UI components are interactable. Younger adults experienced an error rate increase of 80% from skeuomorph to flat interfaces while older adults obtained an increase of 154%. In multiple page navigation tasks, we did not find statistically significant differences between design approaches for younger adults, suggesting that this user group was able to compensate the flat design's limitations by leveraging task-related information. On the other hand, older adults experienced a 2.6-fold increase in error rates from skeuomorph ($M = 13\%$) to flat design ($M = 35\%$).

Design Implication 2 – Younger adults can cope with challenges of flat design: although younger adults experience 'click uncertainty' and are slower in visual search tasks with flat interfaces, results show they are able to cope with these limitations in more complex goal-oriented tasks.

3. What is the user performance difference between older and younger adults when using each of the design approaches?

There is a significant difference in performance between older and younger adults. The former take longer and commit more errors when completing visual search, clicking objects, and multiple page navigation tasks than the latter. Still, the performance gap between younger and older adults is greater in both flat and skeuominimalist designs, making skeuomorph design the optimal approach to reduce the performance gap between age groups.

This result can be justified in part by the higher cognitive load required by flat when compared to skeuomorph interfaces (Burmistrov et al. 2015), which may have a greater impact on the performance of older adults due to a decrease in their perceptual and cognitive abilities (Cansino et al. 2013; Ishihara et al. 2001; Spear 1993). In addition, Zhang, Wang, and Shi (2017) reported that skeuomorph interfaces may ease people's understanding on how to use digital products, which may of greater importance for older adults who are less familiar with technology. Still, further research is needed to understand what specific user characteristics related to aging are more relevant for such difference in performance.

Design Implication 3 – For a compromise solution use skeuomorphic: if designing for a broad age range using a single design style, skeuomorphic interfaces close the performance gap between younger and older adults.

4. What is the aesthetic perception and preference of older and younger adults?

Younger and older participants have clear preferences for skeuominimalist and skeuomorph designs, respectively. Younger users see skeuomorph interfaces as complex and rough, while perceiving skeuominimalist designs as fast and easy to use. This result is in line with prior studies (Li et al. 2014) where flat icons were considered as timeless and simple, but at the cost of identity, interest, and familiarity. This study extends prior knowledge that is centred on younger adults, showing that older adults have mostly opposing views, regarding skeuomorph design as interesting, beautiful, trustworthy, fast and easy to use.

Design Implication 4 – Design skeuominimalist interfaces for younger adults and skeuomorphic for older adults: users' subjective preference may be considered the ultimate design goal when building commercial products for consumer adoption. In this case, younger adults will prefer skeuominimalist interfaces while older adults will choose skeuomorphism.

5.2. Limitations

To guarantee internal validity, we designed a controlled experimental study with three design approaches and a limited number of tasks. However, we acknowledge that further work should investigate whether our findings apply in real-world settings where type of content and task represent the diverse body of user interface designs. Such research should be done in a much larger scale with hundreds of design variations and thousands of participants to help dilute the effects of individual designs. In addition, we did not control for graphic or design familiarity, which may have played a role, for instance, in the identification of icons that are similar to the ones of a particular system (*e.g.* iOS or Android devices). Similarly, fine-grained characteristics of icon design such as shape, line width, or colour could explain some of the results (Cao et al. 2019; Gong et al. 2016). For instance, colour consistency between icons has an impact on visual search efficiency. Users are faster to visually identify icons that look apart, which can explain why flat designs were slower in visual search tasks. Although, investigating age-related differences in fine-grained characteristics of icon design can provide valuable insights, generalising results to the numerous combinations used in design practice is a major challenge. We opted to assess age-related differences in using three overarching design approaches that inherently use colourful icons ranging from skeuomorphism to flat design.

Our study featured a single session, which gives us a snapshot of user performance. It would be interesting to assess user performance over time. A longitudinal study could unveil how differences between design approaches evolve; whether they remain or how they converge over time. If they converge, how long does it take for users to reach similar levels of performance between flat and skeuomorph interfaces? This is particularly relevant as younger users might be more open to innovations and take less time to adapt to technological changes (Pohlmeyer 2012). Yet, this effect may disappear over time (Schneidermeier, Hertlein, and Wolff 2014). In addition, this study presents a clear analysis of the performance and preference of interface designs in laptop computers. Although these results can shed some light on how both user groups may perform overall, further studies are needed to understand the effect of interface design on other platforms (*e.g.* in smartphones or tablets). For instance, while one may expect similar performances in visual search tasks on tablet devices, this may not hold for smartphones due to their smaller form factor.

It is worth highlighting that our older adults group had lower technological expertise than younger participants. In fact, their life experiences with technology are expectedly different. While younger users grew up using computers, older participants had contact with information technologies later on their lives. Thus, it is likely that experience level may be playing a role in our results. We tried to control for expertise measured as the number of years participants have been using technology in general and their experience with specific devices such as computers and tablets. However, we did not find statistically significant correlations between experience with technology and the performance – both in time and error rate – of older adults (nor participants in general) in all tasks – exception made to a negative correlation between the completion time on the multiple page navigation task when using the flat design and older participants' experience with technology. Although this data does not show a clear impact of expertise in user performance, it also does not explain what exactly contributed to the results attained in this study.

Although age is probably not an influence factor per se, but a placeholder for common user characteristics, such as knowledge, habits, abilities, etc. (Vines et al.

2015), further research is needed to understand the effect of each of such characteristics, including expertise.

6. Conclusion

We have investigated user performance and aesthetic perception of younger and older adults with three distinct design approaches: skeuomorph, skeuominimalist, and flat. The study showed that flat design is either slower or less accurate than traditional skeuomorph interfaces across three tasks: visual search, clicking objects and multiple page navigation. User performance differences are particularly noticeable in older adults that can take twice as much time to complete certain tasks and be half as accurate with flat interfaces compared to skeuomorph. The benefits of skeuominimalist interfaces are inconclusive as we did not find a performance gain over flat or skeuomorph designs. On the other hand, skeuomorph interfaces have shown to reduce the performance gap between older and younger participants. Regarding user preference, results show a clear, yet contrasting, choice pattern between age groups; younger adults prefer the skeuominimalist design, while older adults prefer skeuomorph interfaces.

Notes

1. http://belveal.net/2013/03/19/where-have-all-the-affordances-gone, last visited 22/01/2019
2. https://alistapart.com/article/flat-ui-and-forms, last visited 22/01/2019
3. https://www.nngroup.com/articles/windows-8-disappointing-usability, last visited 22/01/2019
4. https://www.cooper.com/journal/2014/01/your-flat-design-is-convenient-for-exactly-one-of-us, last visited 22/01/2019

Acknowledgements

We thank all participants of the user study. This work was partially supported by Fundação para a Ciência e Tecnologia (FCT) through INESC-ID research unit UIDB/50021/2020, LASIGE research unit UIDB/00408/2020, and project ARCADE PTDC/CCI-COM/30274/2017.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was partially supported by Fundação para a Ciência e Tecnologia (FCT) through INESC-ID research unit UIDB/50021/2020, LASIGE research unit UIDB/00408/2020, and project ARCADE PTDC/CCI-COM/30274/2017.

ORCID

João Pedro Vieira Guerreiro http://orcid.org/0000-0002-0952-8368
Hugo Miguel Aleixo Albuquerque Nicolau http://orcid.org/0000-0002-8176-7638

References

Backhaus, Nils, Anna Katharina Trapp, and Manfred Thüring. 2018. "Skeuomorph Versus Flat Design: User Experience and Age-Related Preferences." In *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, edited by Aaron Marcus and Wentao Wang. 10919 LNCS: 527–42. doi:10.1007/978-3-319-91803-7_40.

Banga, Cameron, and Josh Weinhold. 2014. *Essential Mobile Interaction Design: Perfecting Interface Design in Mobile Apps*. Reading, MA: Addison-Wesley, Pearson Education.

Bobeth, Jan, Susanne Schmehl, Ernst Kruijff, Stephanie Deutsch, and Manfred Tscheligi. 2012. "Evaluating Performance and Acceptance of Older Adults Using Freehand Gestures for TV Menu Control." In *Proceedings of the 10th European Conference on Interactive TV and Video*, 35–44. EuroITV '12. New York, NY: ACM. doi:10.1145/2325616.2325625.

Burmistrov, Ivan, Tatiana Zlokazova, Anna Izmalkova, Anna Leonova, Gustavo Desouzart, and Ernesto Filgueiras. 2015. "Flat Design vs Traditional Design: Comparative Experimental Study." In *Human-Computer Interaction – INTERACT* 2015, edited by Julio Abascal, Simone Barbosa, Mirko Fetter, Tom Gross, Philippe Palanque, and Marco Winckler, 9188, 106–114. Cham: Springer International Publishing. doi:10.1007/978-3-319-20889-3_55.

Cabreira, Arthur Theil, and Faustina Hwang. 2018. "Evaluating the Effects of Feedback Type on Older Adults' Performance in Mid-Air Pointing and Target Selection." *Proceedings of the Symposium on Spatial User Interaction - SUI '18, no. October*, 111–119. doi:10.1145/3267782.3267933.

Cansino, Selene, Evelia Hernández-Ramos, Cinthya Estrada-Manilla, Frine Torres-Trejo, Joyce Graciela Martínez-Galindo, Mariana Ayala-Hernández, Tania Gómez-Fernández, et al. 2013. "The Decline of Verbal and Visuospatial Working Memory Across the Adult Life Span." *AGE* 35 (6): 2283–2302. doi:10.1007/s11357-013-9531-1.

Cao, Yaqin, Yi Ding, Yiming Deng, and Xuefeng Zhang. 2019. "Effects of Mobile Application Icon Complexity and Border on College Students' Cognition." In *International Conference on Applied Human Factors and Ergonomics*, edited by Shuichi Fukuda, 273–279. Washington, DC: Springer.

Cho, Minji, Soyoung Kwon, Nooree Na, Hyeon-Jeong Suk, and KunPyo Lee. 2015. "The Elders Preference for Skeuomorphism As App Icon Style." In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, 899–904. CHI EA '15. New York, NY: ACM. doi:10.1145/2702613.2732887.

Crabb, Michael, and Vicki L. Hanson. 2016. "An Analysis of Age, Technology Usage, and Cognitive Characteristics Within Information Retrieval Tasks." *ACM Transactions* *on Accessible Computing* 8 (3): 10:1–10:26. doi:10.1145/2856046.

Creager, James H., and Douglas J. Gillan. 2016. "Toward Understanding the Findability and Discoverability of Shading Gradients in Almost-Flat Design." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 60 (1): 339–343. doi:10.1177/1541931213601077.

Czaja, Sara J., and Chin Chin Lee. 2009. "Information Technology and Older Adults." In *Human-Computer Interaction: Designing for Diverse Users and Domains*, 18–30. Boca Raton, FL: CRC Press.

Findlater, Leah, Jon E. Froehlich, Kays Fattal, Jacob O. Wobbrock, and Tanya Dastyar. 2013. "Age-Related Differences in Performance with Touchscreens Compared to Traditional Mouse Input." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '13*, 343–346. doi:10.1145/2470654.2470703.

Gong, Yong, S.-Y. Zhang, Z.-F. Liu, and F. Shen. 2016. "Eye Movement Study on Color Effects to Icon Visual Search Efficiency." *Journal of ZheJiang University (Engineering Science)* 50 (10): 1987–1994.

Hanson, Vicki L, and Susan Crayne. 2005. "Personalization of Web Browsing: Adaptations to Meet the Needs of Older Adults." *Universal Access in the Information Society* 4 (1): 46–58. doi:10.1007/s10209-005-0110-9.

He, Wan, Daniel Goodkind, and Paul R. Kowal. 2016. *An Aging World:* 2015. United States Census Bureau Washington, DC.

Higgins, James J., and S. Tashtoush. 1994. "An Aligned Rank Transform Test for Interaction." *Nonlinear World* 1 (2): 201–211.

Huppert, Felicia. 2003. "Designing for Older Users." In *Inclusive Design: Design for the Whole Population*, edited by John Clarkson, Simeon Keates, Roger Coleman, and Cherie Lebbon, 30–49. London: Springer. doi:10.1007/978-1-4471-0001-0_2.

Ishihara, Keiko, Shigekazu Ishihara, Mitsuo Nagamachi, Sugaru Hiramatsu, and Hirokazu Osaki. 2001. "Age-Related Decline in Color Perception and Difficulties with Daily Activities–Measurement, Questionnaire, Optical and Computer-Graphics Simulation Studies." *International Journal of Industrial Ergonomics* 28 (3): 153–163. doi:10.1016/S0169-8141(01)00028-2.

Ketcham, Caroline J., and George E. Stelmach. 2001. "Age-Related Declines in Motor Control." *Handbook of the Psychology of Aging* 5: 313–348.

Kohlbacher, Florian, Cornelius Herstatt, and Nils Levsen. 2015. "Golden Opportunities for Silver Innovation: How Demographic Changes Give Rise to Entrepreneurial Opportunities to Meet the Needs of Older People." *Technovation* 39–40: 73–82. doi:10.1016/j.technovation.2014.05.002.

Li, Chun Fu, Hui Ting Shi, Jing Jing Huang, and Lu Ying Chen. 2014. "Two Typical Symbols in Human-Machine Interactive Interface." In *Advanced Design and Manufacturing Technology IV*, 635, 1659–1665. Applied Mechanics and Materials. Trans Tech Publications. doi:10.4028/www.scientific.net/AMM.635-637.1659.

Nagamachi, Mitsuo. 2011. "Kansei/Affective Engineering and History of Kansei/Affective Engineering in the World." *Kansei/Affective Engineering* 13: 1–12.

Nicolau, Hugo, and Joaquim Jorge. 2012. "Elderly Text-Entry Performance on Touchscreens." In *Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility*, 127–134. Boulder, CO: ACM.

Norman, Donald A. 1999. "Affordance, Conventions, and Design." *Interactions* 6 (3): 38–43. doi:10.1145/301153.301168.

Oswald, David. 2018. "Affordances and Metaphors Revisited: Testing Flat vs. Skeuomorph Design with Digital Natives and Digital Immigrants." In *Proceedings of the 32nd International BCS Human Computer Interaction Conference*, 57–68. doi:10.14236/ewic/hci2018.57.

Oswald, David, and Steffen Kolb. 2014, September. "Flat Design vs. Skeuomorphism – Effects on Learnability and Image Attribution in Digital Product Interfaces." In *Proceedings of the 16th International Conference on Engineering and Product Design Education (E&PDE14)*, 402–407. Twente: The Design Society.

Page, Tom. 2014. "Skeuomorphism or Flat Design: Future Directions in Mobile Device User Interface (UI) Design Education." *International Journal of Mobile Learning and Organisation* 8 (2): 130. doi:10.1504/IJMLO.2014.062350.

Pohlmeyer, Anna Elisabeth. 2012. *Identifying Attribute Importance in Early Product Development. Exemplified by Interactive Technologies and Age*. Berlin: Technische Universität Berlin.

Prensky, Marc. 2001. "Digital Natives, Digital Immigrants Part 1." *On the Horizon* 9 (5): 1–6.

Robbins, William H. 2014. *Design Practices In Mobile User Interface*. San Luis Obispo: Graphic Communication Department College of Liberal Arts California Polytechnic State University.

Rogers, Wendy A, Arthur D. Fisk, Anne Collins McLaughlin, and Richard Pak. 2005. "Touch a Screen or Turn a Knob: Choosing the Best Device for the Job." *Human Factors* 47 (2): 271–288. doi:10.1518/0018720054679452.

Salter, K. C., and R. F. Fawcett. 1993. "The Art Test of Interaction: A Robust and Powerful Rank Test of Interaction in Factorial Models." *Communications in Statistics – Simulation and Computation* 22 (1): 137–153. doi:10.1080/03610919308813085.

Schneidermeier, Tim, Franziska Hertlein, and Christian Wolff. 2014. "Changing Paradigm – Changing Experience?" In *Design, User Experience, and Usability. Theories, Methods, and Tools for Designing the User Experience*, edited by Aaron Marcus, 8517 LNCS: 371–382. Cham: Springer International Publishing. doi:10.1007/978-3-319-07668-3_36.

Spear, Peter D. 1993. "Neural Bases of Visual Deficits During Aging." *Vision Research* 33 (18): 2589–2609. doi:10.1016/0042-6989(93)90218-L.

Spiliotopoulos, Konstantinos, Maria Rigou, and Spiros Sirmakessis. 2018. "A Comparative Study of Skeuomorphic and Flat Design From a UX Perspective." *Multimodal Technologies and Interaction* 2 (2): 31. doi:10.3390/mti2020031.

Stickel, Christian, Hans-Martin Martin Pohl, and Jan-Thorsten Thorsten Milde. 2014. "Cutting Edge Design or a Beginner's Mistake? – A Semiotic Inspection of IOS7 Icon Design Changes." In *Design, User Experience, and Usability. User Experience Design for Diverse Interaction Platforms and Environments*, edited by Aaron Marcus, 8518 LNCS: 358–369. Cham: Springer International Publishing. doi:10.1007/978-3-319-07626-3_33.

Stössel, Christian. 2009. "Familiarity As a Factor in Designing Finger Gestures for Elderly Users." In *Proceedings of the 11th International Conference on Human-Computer*

Interaction with Mobile Devices and Services, 78:1–78:2. MobileHCI '09. New York, NY: ACM. doi:10.1145/1613858.1613950.

Vines, John, Gary Pritchard, Peter Wright, Patrick Olivier, and Katie Brittain. 2015. "An Age-Old Problem: Examining the Discourses of Ageing in HCI and Strategies for Future Research." *ACM Transactions on Computer-Human Interaction* 22 (1): 1–27. doi:10.1145/2696867.

Wobbrock, Jacob O., Leah Findlater, Darren Gergle, and James J. Higgins. 2011. "The Aligned Rank Transform for Nonparametric Factorial Analyses Using Only Anova Procedures." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 143–146. doi:10.1145/1978942.1978963.

Wu, Lei, Tian Lei, Juan Li, Bin Li, Subhash Chand, Seema Arti, and Chandra Vijay Chahal. 2015. "Skeuomorphism and Flat Design: Evaluating Users' Emotion Experience in Car Navigation Interface Design." In *Design, User Experience, and Usability: Design Discourse*, edited by Aaron Marcus, 24, 567–575. Cham: Springer International Publishing. doi:10.1007/978-3-319-20886-2.

Xi, Tianyang, and Xiaoli Wu. 2018. "The Influence of Different Style of Icons on Users' Visual Search in Touch Screen Interface." 588: 60582. doi:10.1007/978-3-319-60582-1.

Zhang, Xiaoming, Qiang Wang, and Yan Shi. 2017. "Contrastive Analysis on Emotional Cognition of Skeuomorphic and Flat Icon." In *Advanced Graphic Communications and Media Technologies*. Vol. 417., edited by Pengfei Zhao, Yun Ouyang, Min Xu, Li Yang, and Yujie Ouyang, 225–232. Singapore: Springer. doi:10.1007/978-981-10-3530-2.