Interacting with Computers, vol. 36, no. 1 (2024), pp. 16-29
Author version. Published version available at: https://doi.org/10.1093/iwc/iwae003

Inferior, yet Transformative: The User Experience with Robotic Vacuum Cleaners

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Abstract. Robotic vacuum cleaners are a prime example of home automation and a rich source of information about how people experience it. On the basis of a three-week diary study, this article compares householders' user experience (UX) of robotic vacuum cleaners with their UX of three types of manual vacuum cleaner. The main finding is that robotic vacuum cleaners are inferior in use, yet transform vacuuming. While their inferiority is about their pragmatic qualities, their transformative power relates to their autonomy, agency, and hedonic qualities. This contradictory UX involves that robotic vacuum cleaners perform worse or not at all on seven out of nine surfaces and, at the same time, appear to escalate cleanliness standards. The transformation of household chores such as vacuuming is ongoing and calls for further research on engineering and merging the pragmatic and hedonic aspects of UX.

Keywords: user experience, UX, human-robot interaction, vacuum cleaner, home automation

1 Introduction

Automation shifts work from people to technology and, thereby, changes the task and user experience (UX). The changes include extensive human-automation interaction because automation tends to be partial (Janssen et al., 2019; Sheridan & Parasuraman, 2005). It automates some parts of a task, leaves others unautomated, and may even introduce new sub tasks that require human attention and involvement. This study is about vacuum cleaners, a household appliance that can be either manual or automated. By focusing on household settings, the study bypasses the organizational issues that permeate workplace automation.

Robotic vacuum cleaners are a prime example of home automation and a rich source of information about how people experience it (e.g., Honig et al., 2020; Wellendorf et al., 2022; Yapici et al., 2022). They are a particularly interesting example because vacuuming is a ubiquitous activity that is mostly considered unremarkable, if not tedious, and because studies suggest that robotic vacuum cleaners change vacuuming "from a drudgery to a happy thought" (Sung et al., 2007). That is, they may succeed in adding valued experiential elements to an activity that is performed for purely pragmatic reasons. Klapperich et al. (2020) contend that such additions show how everyday automation can – and should – be designed with well-being in mind. However, direct comparisons between manual and robotic vacuum cleaners are surprisingly rare (for an exception, see Forlizzi, 2007). The present study compares the use of robotic vacuum cleaners with that of other types of vacuum cleaner to investigate how user experiences differ across manual and robotic vacuum cleaners. In addition, this study extends previous UX research by targeting routinized use. While it is well known that UX evolves from early to routinized use (Karahanoğlu & Bakırlıoğlu, 2022; Karapanos et al., 2009), most UX studies investigate the first hours or days of use and may therefore be affected by novelty effects.

To investigate user experiences with robotic vacuum cleaners, this study asks the research question: *Does householders' experience of vacuuming vary across types of vacuum cleaner?* In answering this question, robotic vacuum cleaners are compared with three types of manual vacuum cleaners, namely canister with bag, canister without bag, and upright cordless. It should be noted that this study compares vacuum cleaners at the level of their type; the specific brands and models of the vacuum cleaners are unknown. In addition, vacuuming is divided into activities related to storing, using, maintaining, and repairing the vacuum cleaner. This division is introduced to cover sub tasks automated by robotic vacuum cleaners as well as sub tasks that remain unautomated. Data were collected through a three-week diary study and resulted in the main contribution that robotic vacuum cleaners are inferior, yet transform vacuuming.

2 Related work

UX emerged as a distinct research topic around the turn of the millennium (Bargas-Avila & Hornbæk, 2011; Hassenzahl & Tractinsky, 2006). This section first covers related work on UX, then distinguishes two perspectives on automation, and ends with studies of robotic vacuum cleaners.

2.1 User experience

The ISO 9241-210 (2019) standard defines UX as a "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service". The standard further specifies that the perceptions and responses include "the users' emotions, beliefs, preferences, perceptions, comfort, behaviours, and accomplishments that occur before, during and after use" (ISO 9241-210, 2019). That is, the concept of UX is intentionally broad in scope. It covers all aspects of humans' experiences with technology, including those not covered by the more narrowly scoped concept of usability. Specifically, UX covers both pragmatic and experiential aspects of use. While the pragmatic aspects relate to behavioral goals (so-called "do goals"), the experiential aspects are primarily related to the user's self (so-called "be goals"). In the AttrakDiff model, the experiential aspects are split into two subtypes, thereby yielding a model in which UX consists of three factors (Hassenzahl, 2004):

- *Pragmatic quality*, which is about "the users' need to achieve behavioral goals" (Hassenzahl, 2004). That is, the use of a product has pragmatic quality if the user experiences the product as useful and usable in performing a task. For example, a car possesses pragmatic quality because it is useful for getting from one place to another. Pragmatic quality includes aspects such as whether a product is simple or complicated, practical or impractical, and confusing or clear (Hassenzahl, 2004). Specifically, pragmatic quality covers the traditional usability aspects of effectiveness, efficiency, and learnability.
- *Hedonic identification quality*, which is about "the human need to express one's self through objects" (Hassenzahl, 2004). People express themselves through objects to shape how they appear to themselves and to others. For example, an electric car possesses hedonic identification quality because it signals concern for the environment and adherence to sustainability values. This quality is different from the pragmatic quality of getting to a place where the user needs to go. Hedonic identification quality is for example about whether a product is isolating or integrating and presentable or unpresentable (Hassenzahl, 2004).
- *Hedonic stimulation quality*, which is about "the human need for personal development" (Schrepp et al., 2006). An object can support this need by changing the space of possibilities, creating arousal, providing novel experiences, stimulating creativity, and the like. For example, a person's first car possesses hedonic stimulation quality because it extends the possible destinations of daytrips and thereby provides for pleasant new experiences. Hedonic stimulation quality also includes whether a product is original or typical, standard or creative, and easy or challenging (Hassenzahl, 2004).

The overall contribution of UX research has been to incorporate hedonic – and other non-pragmatic – aspects more fully in our understanding of how technological products are experienced. While pragmatic quality

emphasizes how a product is useful for a task, the two hedonic qualities are open to other relations between the product and its user. For example, hedonic identification may result from a relation that does not involve a task but is solely between the user and product. Ihde (1990) terms this kind of relation an alterity relation. Alterity relations become possible when the product has some level of independence, which is more pronounced in robotic than manual vacuum cleaners. By paying special attention to the hedonic qualities of products, UX research emphasizes that good design is about more than ease and time-savings. This point is particularly important in relation to automation and robots, which are frequently motivated by the vision of relieving the user from work by shifting it to the automated product. For instance, Klapperich et al. (2020) find that contemporary coffee makers, which aim to automate the process as much as possible, degrade UX compared to an experimental coffee maker that kept the user involved in the presumably meaningful elements of the process, that is, grinding the beans and brewing the coffee. In contrast, contemporary coffee makers grind the beans and brew the coffee but leave the dreary elements of the process – cleaning and maintenance – to the user. The authors contend that an unreflective focus on efficiency and pragmatic quality creates flat user experiences and neglects opportunities for using automation to enrich everyday practices such as coffee making.

In addition to coffee makers, UX has also been investigated for a range of other personal and household appliances, including axes (Walsh et al., 2014), companionship robots (Gross et al., 2015), contact lenses (Wirth et al., 2016), juicers (Buxton, 2005), mobile phones (Karapanos et al., 2009), smart-home devices (Chalhoub et al., 2021), and vacuum cleaners (Carames et al., 2021). The UX with all these products has pragmatic as well as hedonic qualities, in different ways and to varying extents. The variations specifically include that UX changes over time. In his study of the UX with mobile phones, Karapanos (2009) divided the first four weeks of use into three phases – orientation, incorporation, and identification – and found that the influence of hedonic stimulation quality on the participants' perception of product goodness decreased after the first phase and became nonsignificant during the third phase. In contrast, hedonic identification quality became a stronger and stronger predictor of perceived goodness from the first to third phase. That is, identification appears more important to long-term UX than stimulation. Similarly, Walsh et al. (2014) find higher mean AttrakDiff ratings for identification than stimulation in their three-month UX study of axe use. In another study, Biduski et al. (2020) find the most satisfying user experiences during the first weeks of using a health-monitoring app, thereby partly suggesting a novelty effect and partly a quick transition to routine use. Kujala and Miron-Shatz (2013) also find the most positive emotions during the early stages of use and conclude that users tended to overestimate their product assessment at this point; in contrast, the importance of pragmatic quality increased over the five-month study period. The impact of extended use is also emphasized by Laban et al. (2022), who find that with repeated interactions users experience better interaction quality in their communication with social robots. Collectively, these studies show that routinized use differs from initial use, thereby highlighting the importance of investigating routinized use, which has so far received less attention in UX studies.

2.2 Perspectives on automation

In UX studies, the investigated technologies are commonly approached as tools. The tool perspective has its roots in craftwork and emphasizes that in skilled use tools are seamless extensions of the users, who attend to their task rather than the tool: When axing, the user's attention is on chopping the wood, not on the axe. When seeing, the user's attention is on the seen objects, not on the contact lenses. It is only upon breakdowns that the tool becomes the focus of attention – becomes present at hand rather than ready to hand (Heidegger, 1962; Verbeek, 2005). If the axe is too small for the lump of wood or the contact lens feels itchy, then the user's attention shifts from the task to the tool. Control remains with the user during both use and breakdowns. From a tool perspective, automation is about skilled use during which the tool recedes into the background of attention – becomes transparent.

Breakdowns thwart progress on the task, at least temporarily, and therefore cause frustration, which is a common user experience (Hertzum & Hornbæk, 2023). Importantly, the cause of the frustration is not the extra time spent but the impression of spending it on something that unexpectedly and unnecessarily takes time away from the task. To provide good UX, designs should shorten interactions that are not perceived as meaningful, such as breakdowns and maintenance, but may deliberately prolong the meaningful moments of the task (Grosse-Hering et al., 2013; Klapperich et al., 2020). Prolonging the meaningful moments makes more room for the kinds of experiences we appreciate, such as immersion and stimulation. For example, the participants in the study by Klapperich et al. (2020) expressed that they liked to "take time" for the interactions with the experimental coffee maker, which resulted in longer task completion times than with the contemporary coffee maker. In contrast, they appreciated the contemporary coffee maker for its ability to "save time", for example in the morning. That is, the experimental coffee maker was less efficient but more satisfying to use. Such contradictions between efficiency and satisfaction are not uncommon. In a review of studies that compared systems on both efficiency and satisfaction, Nielsen and Levy (1994) found that in 25% of the 113 comparisons the users preferred the system with which they were slower.

Contemporary coffee makers represent a system perspective that is common in work settings. While the tool perspective makes automation a matter of skilled use during which the tool becomes transparent, the system perspective achieves automation by allocating fewer functions to humans and more to automated components. The allocation of functions to either humans or automation is determined by differences in what humans and automation do best and, therefore, evolves with the emergence of new technological options (Price, 1985). Automation does not mean that humans disappear from the systems. On the contrary, human users interact with automation in various ways (Janssen et al., 2019; Sheridan & Parasuraman, 2005). However, the focus in the evolutions tends to be on achieving more effective and efficient performance (Roto et al., 2019). Other criteria for making allocation-of-function decisions tend to remain secondary in the system perspective. These criteria include: "opportunity to exercise specialist skills", "having a variety of work to do", "enjoying interactions with other people", "working as a member of a team", "status gained from being a source of important information", "knowing what is going on", and "challenge of dealing with difficult problems" (Marsden & Kirby, 2005).

The performance thinking that typically drives the system perspective has made its way into models of how people experience technologies. For example, the widely applied technology acceptance model assigns primacy to perceived usefulness and perceived ease of use (Davis, 1993). Perceived enjoyment is included in only a small subset of technology acceptance studies but found to exert considerable influence on people's intention to adopt and use a technology (Hornbæk & Hertzum, 2017). Furthermore, people are more likely to accept a technology if they perceive that they have control over it and the data it produces (Abraham et al., 2019). This finding appears important in relation to automation because much automation shifts control away from shopfloor employees. When UX is studied in work settings, several studies find that unremarkable and ordinary user experiences dominate (Clemmensen et al., 2020; Meneweger et al., 2018). For example, Clemmensen et al. (2020) find that during continued technology use employees' UX "is middle-of-the-scale, remains largely constant over time, and varies little across use situations". It may be tempting to assume that vacuuming resembles work in this respect. If so, it differs from the non-work activities that are investigated in most UX studies. These studies tend to give prominence to affective and positive experiences.

2.3 Robotic vacuum cleaners

Cleaning is a common household chore, which is often seen as tedious and repetitive. Thus, there is a large market for vacuum cleaners that promise to automate vacuuming. The global market for robotic vacuum cleaners was valued at USD 1.84 billion in 2018 and is forecasted to reach USD 4.98 billion by 2025 (Statista, 2022). In contrast to this bright forecast, Carames et al. (2021) conclude that new users of robotic vacuum cleaners are more satisfied than experienced users. This finding echoes Fink et al. (2013), who find that after six months two (of nine) households had completely stopped using their robotic vacuum cleaner, four

households used it sporadically, and only three households had integrated it in their cleaning practices. The most common problems described with robotic vacuum cleaners in online reviews are that they get stuck, require a lot of maintenance, must be supervised by the user, do not return to the charging dock, move randomly in the space, leave uncleaned spots, are noisy, and bump into walls and objects (Honig et al., 2020).

A prevalent finding in previous studies of robotic vacuum cleaners is that they are not merely tools. On the one hand, users often describe their robotic vacuum cleaner as a tool and, for example, state that "I prefer to be the one in control" (Wellendorf et al., 2022). On the other hand, users simultaneously anthropomorphize the vacuum cleaner by giving it a name, a gender, and sometimes even a status in the family (Hendriks et al., 2011; Sung et al., 2007; Wellendorf et al., 2022; Yapici et al., 2022). The anthropomorphizing is specific to robotic vacuum cleaners; in Forlizzi's (2007) comparison of robotic and upright cordless vacuum cleaners, none of the upright cordless vacuum cleaners were anthropomorphized. In continuation of the anthropomorphizing, Hendriks et al. (2011) investigated what kind of personality a robotic vacuum cleaner should have and found that people prefer "a calm, polite, and cooperative robot vacuum cleaner that works efficiently, systematically and likes routines". These studies show that robotic vacuum cleaners are not tools in the sense of being transparent devices that extend the user's capabilities without calling attention to themselves. Rather, people develop relationships at some level of intimacy with their robotic vacuum cleaner. In Ihde's (1990) terms, these relationships are alterity relations; they are relations to the vacuum cleaner itself rather than relations through it to the task of vacuuming. In addition, people develop new cleaning practices. Some of these practices exploit the autonomy of the robotic vacuum cleaner to increase multitasking: "I can be dusting while the floors are being cleaned" (Forlizzi, 2007). Others involve escalated standards of cleanliness (Nicholls & Strengers, 2019) or changes in general housekeeping practices to accommodate the vacuum cleaner by keeping the floors free of obstacles: "I think it definitely motivates us to tidy up" (Yapici et al., 2022).

3 Method

Collectively, the studies reviewed above show that robotic vacuum cleaners are not merely tools but cannot be understood from a system perspective either. To investigate how householders experience robotic as opposed to manual vacuum cleaners, this study engaged 24 participants in a 3-week diary study of their vacuuming UX.

3.1 Participants

Participants were recruited from three European countries. A multinational sample was considered important because household chores such as vacuuming might vary across cultures. Eight participants were from France, eight from the Netherlands, and eight from Portugal. All participants had used their vacuum cleaner long enough for practices to settle and become routine. Participant recruitment aimed for variation across the categories in Table 1. With small cross-country variations, the participants were evenly distributed between the age groups of 20-39 and 40-59 years and between female and male participants. In addition, most participants lived in homes that were 100-199 m^2, about half of the participants had children in the household, and half of the participants were pet owners. The majority of the participants had one vacuum cleaner but a large minority of ten participants had two or three vacuum cleaners.

Table 1. Participant profile

Category		France	Netherlands	Portugal
Age (years)	20-39	3	4	5
	40-59	5	3	3
	60-79	0	1	0
Gender	Female	5	4	5
	Male	3	4	3
Size of home (m^2)	50-99	3	2	2
	100-199	5	6	6
Children at home	Yes	6	4	3
	No	2	4	5
Pet owner	Yes	5	4	4
	No	3	4	4
Number of vacuum cleaners	1	6	5	3
	2	1	2	5
	3	1	1	0

3.2 Vacuum cleaners

Four types of vacuum cleaner were included in the study: canister with bag, canister without bag, upright cordless, and robotic vacuum cleaners. Table 2 specifies the features of each type. The participants used a total of 36 vacuum cleaners, which were almost evenly distributed across the three countries and the four vacuum-cleaner types, see Table 3. The ten participants who had more than one vacuum cleaner comprised four participants with a canister without bag and a robotic vacuum cleaner, two participants with a canister with bag and an upright cordless, one participant with a canister with bag and a robotic vacuum cleaner, one participant with an upright cordless and a robotic vacuum cleaner, one participant with a canister with bag, an upright cordless, and a robotic vacuum cleaner, and one participant with a canister without bag, an upright cordless, and a robotic vacuum cleaner.

Table 2. The four types of vacuum cleaner included in the study

Type	Example	Key features
Canister with bag		• Collects dirt in a bag, which must be replaced when full • Gets electric power through a cord • Is moved around on its wheels • Can be stored whereever there is space for it
Canister bagless		• Collects dirt in a container, which must be emptied when full • Gets electric power through a cord • Is moved around on its wheels • Can be stored wherever there is space for it
Upright cordless		• Collects dirt in a container, which must be emptied when full • Gets electric power from a battery • Is carried around or moved around on wheels in the nozzle • Must be stored in dock to recharge
Robot		• Collects dirt in a container, which must be emptied when full • Gets electric power from a battery • Moves around by itself • Must be stored in dock to recharge

Table 3. Distribution of the four types of vacuum cleaner across the three countries

Type of vacuum cleaner	France	Netherlands	Portugal	Total
Canister with bag	3	3	3	9
Canister bagless	3	3	4	10
Upright cordless	3	3	3	9
Robot	2	3	3	8
Total	11	12	13	36

3.3 Procedure

The data were collected in 2022 by International Consumer Research and Testing (ICRT, https://www.international-testing.org) and subsequently made available for this study. ICRT's member associations in France, the Netherlands, and Portugal assisted in recruiting the participants, but ICRT had the user-research consultancy Design Psychology administer the data collection. For each participant, the data collection involved a three-week diary study. A diary study (Lazar et al., 2017) had the advantage that it allowed for collecting data about the participants' vacuuming as it occurred in its naturalistic setting over a multi-week period. The concurrent data collection obtained with diaries was considered a feasible means of combating inflated or otherwise inaccurate answers. It should, however, be noted that the diaries were more structured in their coverage of pragmatic than hedonic quality.

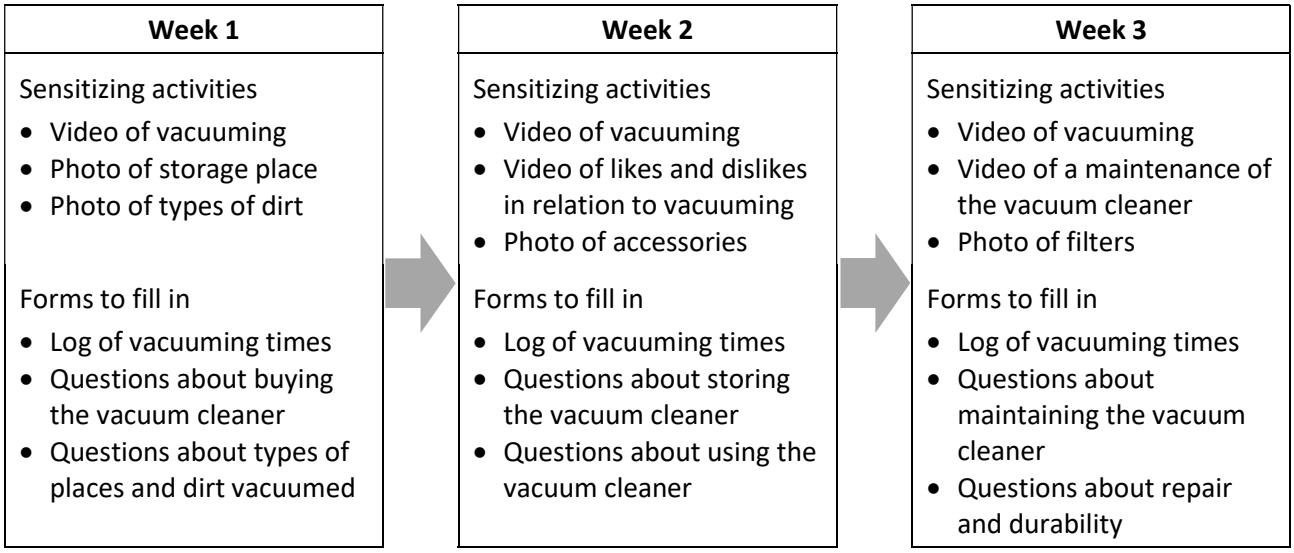

Figure 1. The activities in each week of the diary study

The diary study consisted of sensitizing activities and forms to be filled in, see Figure 1. The sensitizing activities served to make the participants conscious of the steps and activities involved in vacuuming. This was deemed advantageous because vacuuming is a routine activity that may otherwise recede into the background, thereby making it difficult to answer questions about it. During the first week, the participants were to video-record their vacuuming and take photos of the storage place for their vacuum cleaner and the types of places and dirt they vacuumed. These activities sensitized them to the study in general and to answering questions about where and what they vacuumed. During the second week, the participants were to video-record their likes and dislikes in relation to vacuuming and take photos of their vacuum accessories, such as nozzles and brushes. This week they answered questions about storing and using their vacuum cleaner. During the third week, the participants were to video-record a maintenance of their vacuum cleaner and take photos of its different filters. These activities sensitized them to answering questions about maintenance and repair.

The forms included that the participants were to log when and for how long they vacuumed. The forms also asked the participants for information about the places they vacuumed and about their storing, use, maintenance, and repair of their vacuum cleaner. Because the different types of vacuum cleaner had different features, many questions were specific to the type of vacuum cleaner. The present analysis was restricted to 32 questions that were common to the four types. These questions consisted of 1 question that involved logging the frequency and duration of vacuuming, 18 questions that were to be answered on 11-point rating scales with labelled endpoints, and 13 questions that required free-text answers. The rating-scale questions were about overall, task-specific, and feature-specific UX. The free-text questions were about the individual steps involved in vacuuming (i.e., storing, using, maintaining, and repairing), supplemented with a question for any additional comments. Eight of the free-text questions were pairs of questions that asked participants about their positive, respectively negative, experiences at each of the four steps. For example, the pair of questions about maintaining the vacuum cleaner asked “What do you find good, easy or enjoyable?” and ”What do you find bad, difficult or annoying?” about the following activities: “Changing the dust bag”/”Emptying the dust container”, “Cleaning the filter”, “Cleaning the nozzle”, and “Cleaning the neck”.

All instructions to the participants about what to do during the diary study were collected in a printed booklet with a section for each week. The booklet instructed the participants about the sensitizing activities and contained the forms to be filled in. Participants who owned multiple types of vacuum cleaner received a booklet for each of them. In the booklet, the purpose of the study was explained in this way: "We aim to understand how you use your vacuum cleaner, what you like, dislike, and what is important to you about it." The booklet was created and pilot-tested in English; then it was translated into the participants' native language (French, Dutch, and Portuguese).

Once they had been recruited, the participants received an introductory phone call from Design Psychology to explain the study, answer any questions, and obtain informed consent. Then, the three-week diary period started. At the end of each week, participants were to send the videos, photos, and filled-in forms for that week to Design Psychology. This weekly contact with the participants served to maintain their motivation and provided an opportunity to spot misunderstandings and step in with feedback. A few participants received such feedback; most participants completed their diaries without further personal interaction after the introductory phone call. Participants received about 70 euros for their participation in the study.

3.4 Data analysis

The 18 rating-scale questions were analyzed quantitatively with the vacuum cleaner as the unit of analysis. To test for differences among the types of vacuum cleaner, we conducted analyses of variance (ANOVAs). Follow-up pairwise comparisons used the least significant difference (LSD) method because Bonferroni adjustment was considered overly conservative. In addition, we used Pearson partial correlations (r_p) to test whether the participants' general happiness with their vacuum cleaner was mainly determined by ease of storing, ease of using, or ease of maintaining. The use of partial correlations was motivated by covariation in the participants' ratings of the ease of storing, using, and maintaining. Partial correlations measure the strength of the relationship between two variables whilst controlling for the effect of other variables, thereby partialing out the covariation.

The answers to the 13 free-text questions were collapsed into one pool and content analyzed (Lazar et al., 2017). As a precursor to this analysis, the answers were translated from the participants' native language into English. Then the content of each answer was split into its constituent elements. For example, the answer "Because it's unpleasant and heavy, short cord range" was split into "unpleasant", "heavy", and "short cord". This way, the answers to the free-text questions were split into 952 answer elements, which were afterward sorted into groups. First, we sorted the 952 answers into positive and negative experiences. Eight questions explicitly asked for either positive or negative experiences. For these questions, the participants had provided the sorting. For the remaining five questions, the content of the answers was analyzed. For example, "unpleasant", "heavy", and "short cord" were all categorized as negative. Second, we sorted the 952 answers deductively into the three AttrakDiff categories (for definitions, see Section 2.1). For example, "unpleasant" was categorized as hedonic stimulation quality because it was about (failure in) the be-goal of experiencing arousal, creativity, and development. In contrast, "heavy" and "short cord" were categorized as pragmatic qualities because they were about (inadequacies in) the usefulness and usability of the vacuum cleaner to the vacuuming task. Subsequently, chi-square (χ^2) tests were used to test for differences in the distribution of AttrakDiff categories and positive/negative experiences across the vacuum-cleaner types. Third, we sorted the 952 answers inductively into groups of related content and gave each group a descriptive label. For example, "short cord" went into a group labelled 'inconvenient' along with answers such as "bumps into objects" and "not practical".

Finally, the photos and videos from the participants' sensitizing activities were inspected for supplementary information about two issues: the tasks for which the vacuum cleaners were used (i.e., the objects vacuumed) and the place at which the vacuum cleaners were stored when they were not in use. For both issues, the inspection was documented separately for each vacuum cleaner.

4 Results

To investigate robotic vacuum cleaners, the participants' vacuuming UX was analyzed quantitatively and qualitatively. In the quantitative analyses, statistical significance was set at the level of .05.

4.1 Frequency and duration of vacuuming

Table 4 summarizes the participants' logs of when and for how long they vacuumed. Overall, the vacuum cleaners were used a mean of 2.74 times a week. However, the frequency of use depended on the type of vacuum cleaner, $F(3, 32) = 2.97$, $p = .046$. LSD-based pairwise comparisons showed that robotic vacuum cleaners were used significantly more often than vacuum cleaners of the types canister with bag and canister without bag. Similarly, the duration of use depended on the type of vacuum cleaner $F(3, 32) = 3.25$, $p = .035$. LSD-based pairwise comparisons showed that robotic vacuum cleaners were used for significantly more minutes a week than the three other types of vacuum cleaner. The difference was large. While the robotic vacuum cleaners were used for about half an hour a day, the other vacuum cleaners were used for about half an hour a week. In addition, the larger standard deviation for the robotic vacuum cleaner indicated larger cross-participant variation in the use of this type of vacuum cleaner than in the use of the other types.

Table 4. Frequency and duration of vacuuming (mean and, in parentheses, standard deviation)

Question	Canister with bag *N* = 9	Canister bagless *N* = 10	Upright cordless *N* = 9	Robot *N* = 8	Total *N* = 36
Frequency (times/week) *	2.02 (1.23)	1.43 (1.34)	2.91 (1.85)	5.00 (4.93)	2.74 (2.87)
Duration (minutes/week) *	26.06 (18.49)	30.63 (19.29)	28.19 (39.86)	218.29 (320.37)	70.58 (165.77)

Note: * $p < .05$ (analysis of variance)

4.2 Overall UX

The participants rated their general happiness with their vacuum cleaner to a mean of 7.06, see Table 5. Happiness did not vary across vacuum-cleaner types, $F(3, 31) = 1.84$, $p = .161$. Participants also rated how easy they found it to store, use, and maintain their vacuum cleaner. The mean ratings were 6.69, 7.14, and 6.29, respectively. Ease of use varied across vacuum-cleaner types, $F(3, 31) = 2.91$, $p = .049$. LSD-based pairwise comparisons showed that upright cordless vacuum cleaners were significantly easier to use than vacuum cleaners of the types canister with bag and without bag. Ease of storing and maintaining did not vary across vacuum-cleaner types, Fs(3, 31) = 2.34 and 1.18, respectively (both ps > .09).

Table 5. Overall experience of vacuum cleaner (mean and, in parentheses, standard deviation)

Question	Canister with bag *N* = 9	Canister bagless *N* = 10	Upright cordless *N* = 9	Robot *N* = 7	Total *N* = 35
How happy are you with your vacuum cleaner in general? (0: very unhappy – 10: very happy)	6.78 (2.05)	7.60 (2.41)	7.89 (1.97)	5.57 (2.07)	7.06 (2.22)
Overall, how easy is it to store your vacuum cleaner? (0: very difficult – 10: very easy)	6.11 (1.69)	5.70 (2.71)	8.11 (1.90)	7.00 (1.92)	6.69 (2.25)
Overall, how easy is it to use your vacuum cleaner? (0: very difficult – 10: very easy) *	6.22 (1.72)	6.60 (2.37)	8.78 (0.83)	7.00 (2.71)	7.14 (2.16)
Overall, how easy is it to maintain your vacuum cleaner? (0: very difficult – 10: very easy)	6.44 (1.74)	6.50 (2.17)	6.89 (1.62)	5.00 (2.83)	6.29 (2.11)

Note: * $p < .05$ (analysis of variance)

The participants' ratings of the ease of storing, using, and maintaining their vacuum cleaner covaried significantly, rs > .34 (all ps < .05). This covariation motivated the use of partial correlations to analyze whether the participants' general happiness with their vacuum cleaner was mainly determined by ease of storing, using, or maintaining. Table 6 shows that the participants' general happiness with their vacuum cleaner was mainly determined by its ease of use. The partial correlation between general happiness and ease of use, when controlling for ease of storing and maintaining, was strong and significant, $r_p(33) = .71$, $p < .001$. In contrast, the partial correlation between general happiness and ease of maintaining, when controlling for ease of storing and using, was not significant, $r_p(33) = .22$, $p = .218$. Finally, the partial correlation between general happiness and ease of storing, when controlling for ease of using and maintaining, was negative and significant, $r_p(33) = -.46$, $p = .007$. This negative correlation indicated that ease of storing was trumped by ease of using and maintaining as determinants of general happiness with the vacuum cleaner. Separate analyses for each of the four types of vacuum cleaner showed the same pattern of results as for the four types together, see Table 6.

Table 6. Partial correlation with the question "How happy are you with your vacuum cleaner in general?"

Question	Canister with bag *N* = 9	Canister bagless *N* = 10	Upright cordless *N* = 9	Robot *N* = 7	Total *N* = 35
Overall, how easy is it to store your vacuum cleaner? (0: very difficult – 10: very easy)	-.67	-.23	-.29	-.47	-.46**
Overall, how easy is it to use your vacuum cleaner? (0: very difficult – 10: very easy)	.89**	.77*	.31	.65	.71***
Overall, how easy is it to maintain your vacuum cleaner? (0: very difficult – 10: very easy)	-.28	.01	.21	.36	.22

Note: * $p < .05$, ** $p < .01$, *** $p < .001$ (Pearson partial correlation)

4.3 Task-specific UX

Table 7 shows how happy the participants were with their vacuum cleaner for specific tasks. The number of answers to these questions varied because each participant used their vacuum cleaner for only some of the

nine tasks. For hard floors, rugs, crevices, and thresholds, the participants' vacuuming UX differed across the types of vacuum cleaner (hard floors: $F(3, 29) = 4.02$, $p = .017$; rugs: $F(3, 24) = 4.06$, $p = .018$; crevices: $F(3, 17) = 5.05$, $p = .011$; thresholds: $F(3, 12) = 4.44$, $p = .026$). For all four of these tasks, LSD-based pairwise comparisons showed that participants were significantly less happy with the robotic vacuum cleaner than with the three other vacuum-cleaner types. For the five other tasks, there was no difference in the participants' vacuuming UX across vacuum-cleaner types (behind/under furniture: $F(3, 27) = 1.28$, $p = .302$; carpets: $F(3, 22) = 2.13$, $p = .125$; ceiling/corners: $F(2, 13) = 0.35$, $p = .713$; stairs: $F(2, 9) = 0.19$, $p = .832$; objects: $F(2, 7) = .18$, $p = .842$). However, the robotic vacuum cleaner was not used at all for three of these tasks: ceiling/corners, stairs, and objects. In addition to these three tasks, the analysis of the photos and videos from the participants' sensitizing activities showed that the three manual vacuum-cleaner types were used for many further tasks that could not be performed by the robotic vacuum cleaners. These tasks included vacuuming walls, windowsills, window blinds, stoves, fireplaces, bathtubs, toilet seats, tabletops, shelves, chairs, sofas, beds, pillows, and the interior of cars.

Table 7. Task-specific experience of vacuuming (mean and, in parentheses, standard deviation of answers to the question "How happy are you with your vacuum cleaner for cleaning <surface>?"), all questions answered on an 11-point scale (0: very unhappy – 10: very happy)

Surface	Canister with bag	Canister bagless	Upright cordless	Robot	Total
Hard floors, *N* = 33 *	8.38 (1.19)	8.33 (1.58)	8.78 (0.83)	6.14 (2.61)	8.00 (1.84)
Behind/under furniture, *N* = 31	6.62 (2.39)	6.67 (2.65)	5.63 (2.67)	4.00 (3.95)	5.87 (2.92)
Rugs, *N* = 28 *	7.83 (2.48)	8.13 (2.23)	6.50 (3.02)	3.33 (3.20)	6.57 (3.18)
Carpets, *N* = 26	7.38 (2.50)	8.17 (0.75)	6.50 (3.21)	4.50 (3.46)	6.69 (2.85)
Crevices, *N* = 21 *	7.17 (1.84)	7.50 (1.64)	6.00 (3.89)	1.00 (1.00)	6.05 (3.20)
Thresholds, *N* = 16 *	7.00 (1.90)	7.75 (0.96)	5.75 (3.59)	1.00 (1.41)	6.12 (2.94)
Ceiling/corners, *N* = 16	7.00 (3.56)	7.57 (1.72)	6.20 (3.42)	-	7.00 (2.68)
Stairs, *N* = 12	6.50 (2.08)	7.00 (3.16)	7.50 (1.29)	-	7.00 (2.13)
Objects, *N* = 10	6.33 (0.58)	5.25 (2.22)	5.67 (3.51)	-	5.70 (2.16)

Note: * $p < .05$ (analysis of variance)

4.4 Feature-specific UX

Table 8 shows the participants' experience of five features common to all four types of vacuum cleaner. The participants were happy, but not very happy, with the size of their vacuum cleaner. In contrast, their experiences of the noise level, the storing of accessories, and the purchase of filters and accessories were close to the neutral midpoint of the scale. There were no differences across vacuum-cleaner types for any of the five features (size: $F(3, 32) = 1.44$, $p = .249$; noise level: $F(3, 32) = 1.46$, $p = .887$; storing accessories: $F(3, 30) = 1.69$, $p = .189$; finding filters: $F(3, 24) = 0.99$, $p = .412$; finding accessories: $F(3, 24) = 1.60$, $p = .216$).

Table 8. Feature-specific experience of vacuuming (mean and, in parentheses, standard deviation)

Surface	Canister with bag	Canister bagless	Upright cordless	Robot	Total
How happy are you with the size of your vacuum? (0: very unhappy – 10: very happy), *N* = 36	6.22 (2.05)	6.90 (3.35)	8.44 (1.24)	7.63 (2.26)	7.28 (2.43)
How happy are you with the noise level? (0: very unhappy – 10: very happy), *N* = 36	5.11 (2.32)	5.20 (3.23)	6.00 (2.40)	5.38 (2.33)	5.42 (2.53)
How easy is it to store different accessories? (0: very difficult – 10: very easy), *N* = 34	4.11 (2.76)	6.90 (2.96)	5.44 (2.83)	4.50 (3.02)	5.35 (2.97)
How easy is it to find the filters in shops? (0: very difficult – 10: very easy), *N* = 28	5.00 (1.00)	6.50 (2.67)	6.38 (1.51)	5.00 (3.11)	5.71 (2.19)
How easy is it to find accessories and parts in shops? (0: very difficult – 10: very easy), *N* = 28	5.43 (2.51)	6.50 (2.74)	6.38 (2.20)	4.00 (2.24)	5.57 (2.49)

4.5 Pragmatic and hedonic qualities

The participants qualitative answers were not evenly distributed across pragmatic quality, hedonic identification quality, and hedonic stimulation quality, $\chi^2(2, N = 952) = 1013.08$, $p < .001$. Table 9 shows that five in six answers were about pragmatic quality (82%); there were about equally many answers about identification (8%) and stimulation (11%). The distribution of answers across the three AttrakDiff categories differed for the four vacuum-cleaner types, $\chi^2(6, N = 952) = 16.25$, $p = .012$. Follow-up *z*-tests showed that the proportion of answers about identification was significantly lower for robotic vacuum cleaners (5%) than for canister bagless (10%) and that the proportion of answers about stimulation was significantly higher for robotic vacuum cleaners (16%) and upright cordless (14%) than for canister with bag (8%) and canister bagless (8%).

Table 9. Distribution of qualitative answers across the three AttrakDiff categories, *N* = 952 answers

Category	Canister with bag		Canister bagless		Upright cordless		Robot		Total	
	N	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*
Pragmatic quality	230	85	240	82	177	80	133	79	780	82
Hedonic identification quality *	21	8	29	10	14	6	8	5	72	8
Hedonic stimulation quality *	21	8	22	8	30	14	27	16	100	11

Note: * $p < .05$ (*z*-test)

4.6 Groups of qualitative answers

The qualitative answers spanned a range of groups within each of the AttrakDiff categories, see Table 10.

Table 10. Groups of qualitative answers within the AttrakDiff categories, *N* = 952 answers

Category	Positive groups	Negative groups
Pragmatic quality	Easy (196), Convenient (35), Quick (28), Effective (19), Suction power (19), Accessible (17), Efficient (15), Maintenance rarely needed (12), Price (11), Automatic (10), Size (10), Intuitive (9), Durable (8), Light (8), Adjustable (7), Ergonomic (5), Reliable (5), Versatile (5), Battery life (3), Good service (2)	Difficult (98), Inconvenient (27), Cannot vacuum some types of dirt (25), Ineffective (22), Suction power (20), Size (18), Not functioning properly (16), Price (15), Heavy (14), Nowhere to store (14), Inefficient (13), Maintenance often needed (13), Not durable (13), Dust spill (11), Not easily accessible (10), Dirty (8), Not ergonomic (8), Not adjustable (5), Battery life (4), Not child-safe (2)
Hedonic identification quality	Brand and country (38), Ecofriendly (14), Part of the family (1)	Not ecofriendly (11), Brand and country (8)
Hedonic stimulation quality	Good (23), Pleasant (14), Aesthetic (2), Love it (2), Satisfied (2)	Annoying (30), Unpleasant (12), A hassle (5), Bad (5), Uncomfortable (4), Not aesthetic (1)

Note: The numbers in parentheses give the number of answers in each group

4.6.1 Pragmatic quality

Independent of AttrakDiff category, the two most frequent groups were “Easy” and “Difficult”. This pair of groups accounted for 31% of the 952 qualitative answers and spanned a well-known pragmatic-quality dimension. Other well-known pragmatic-quality dimensions were also prominent, including convenience, effectiveness, accessibility, efficiency, and ergonomics. Participants mentioned these groups with similar frequency in positive and negative answers. That is, they experienced convenience about as often as inconvenience, and so forth. In addition, a number of groups were specific to storing, using, and maintaining the vacuum cleaners.

First, several groups were about the size of the vacuum cleaners and the associated problems with finding an appropriate place to store them (and the accessories). Storage problems were also pronounced for robotic vacuum cleaners because they needed free access to the charging dock to be able to return to it automatically, thereby often precluding out-of-sight storage. One participant commented: “We had no other choice but storing it in the living room”. The analysis of the photos and videos elaborated this comment. The vacuum cleaners were either stored out of sight (i.e., in cabinets, utility rooms, or bedrooms) or in plain sight (i.e., in the entrance, kitchen, children’s room, or living room). However, the storage location varied by vacuum-cleaner type. Only 1 of the 19 vacuum cleaners of the types canister with bag and without bag was stored in plain sight. In contrast, the two vacuum-cleaner types that had to be stored in a charging dock were stored in plain sight in six of nine (upright cordless) and five of eight (robot) instances.

Second, multiple answers about using the vacuum cleaners concerned their suction power and their inability to vacuum hot, humid, sticky, and big dirt, such as ash, pet food, soft drinks, and leaves. Several participants with robotic vacuum cleaners also noted problems with vacuuming hair (e.g., “hair will curl tightly around it [i.e., the brush] and can't be removed”). Furthermore, the robotic vacuum cleaners were considered ineffective and inefficient because they bumped into things (e.g., “Does not work very well, it rides over things”), got stuck (e.g., “It always gets stuck at the same chair”), got lost (e.g., “Sometimes it gets a bit lost. Then it takes an illogical route back to the charging dock”), and did not vacuum everywhere (e.g., “The robot often skips the corners and whole sections of the room”). At the same time, the groups about using the vacuum cleaners contained a positive category specific to the robotic vacuum cleaners; their automatic mode of operation was appreciated (e.g., “I don't have to do anything”).

Third, multiple answers concerned the maintenance of the vacuum cleaners, including frequent dust spills when replacing the bag/emptying the container (e.g., “A lot of dust can escape from the bag”) and problems preventing the vacuum cleaner from becoming dirty (e.g., “I have the feeling that it [i.e., the outside filter] is always dirty”). Furthermore, the videos of maintaining the robotic vacuum cleaners showed the participants in the active role of emptying the dust container, cleaning the brushes, and otherwise caring for the vacuum cleaner, which on these occasions displayed no robotic qualities. In contrast, the videos of vacuuming with the robotic vacuum cleaners showed a task that was delegated to the vacuum cleaner to the extent of leaving the participants with no other role than video-recording its performance and occasionally removing an obstacle from the floor.

4.6.2 Hedonic identification quality

The participants mainly experienced two hedonic identification qualities with their vacuum cleaners. Both these qualities were experienced as positively present by some participants and negatively absent by others. First, multiple participants associated certain brands and countries of manufacture with good quality and others with poor quality. For example, one participant wrote: “Dyson -> their reputation”. Another participant noted: “I prefer a European vacuum”. In contrast, a participant avoided vacuum cleaners from “countries with bad working conditions”. It should be noted that the specific country preferences might reflect that the participants were Europeans. Second, the participants cared about whether their vacuum cleaner was ecofriendly. Several participants had chosen a bagless vacuum cleaner for at least in part environmental reasons, for example one participant stated: “I no longer want to use bags because I care about the environment.” Another participant noted: “I think the robot uses less energy than the [participant’s other] vacuum cleaner”. In contrast, several other participants were concerned about the number of plastic parts, which did not seem very sustainable. Others mentioned a conflict between good suction power and low energy consumption (e.g., “Probably energy-consuming but efficient”). In addition to these two hedonic identification qualities, one participant wrote that their robotic vacuum cleaner “even has a name, she is part of the family.” In another comment, the same participant wrote: “When Rosie [i.e., the vacuum cleaner] got repaired we really missed her”. Such affective and anthropomorphic remarks were restricted to robotic vacuum cleaners. The three other types of vacuum cleaner were never anthropomorphized.

4.6.3 Hedonic stimulation quality

The hedonic stimulation qualities experienced with the vacuum cleaners ranged from overall qualities of good or bad, over more specific qualities such as pleasant or unpleasant, to whether the vacuum cleaner had an aesthetic appearance. The most expressly positive answers were the two in the ‘love it’ category. A participant with a robotic vacuum cleaner answered: “I need to empty the dust container often, but I do this with love, because it makes me realize that I don’t have to vacuum myself”. The second answer in this category was about a canister without bag. Several other participants linked positive stimulation qualities to pragmatic qualities (e.g., “I am satisfied because it is useful and practical”). With respect to negative stimulation qualities, multiple participants had issues with the cord (e.g., taking it out, plugging it in, stopping to unplug it, and replugging it somewhere else): “It is a hassle, why can't this be easier?” Other participants were annoyed about changing the dust bag, emptying the container, cleaning the filters, disassembling the vacuum cleaner after use, or finding accessories in shops. Finally, a few answers concerned the aesthetics of the vacuum cleaner, especially when it could not be stored out of sight: “Not everyone has a storage space, so a nice color or a pretty dock are nice-to-haves”.

4.7 Preference

The 14 participants with one vacuum cleaner were evenly divided between canister with bag (5), canister bagless (5), and upright cordless (4); none of them had a robotic vacuum cleaner. The eight participants with a robotic vacuum cleaner also had other vacuum cleaners. All eight participants with a robotic vacuum cleaner rated it lower than their other vacuum cleaner(s) on the question “How happy are you with your

vacuum cleaner in general?" Thus, the robotic vacuum cleaners were always supplemental and never preferred.

5 Discussion

The results combine into the overall finding that robotic vacuum cleaners are inferior in pragmatic quality, yet transform vacuuming. This contradictory UX deserves attention because it sheds light on the dynamics between pragmatic and hedonic qualities.

5.1 Transformative power

The transformative power of robotic vacuum cleaners relates to their autonomy and agency. Robotic vacuum cleaners offer a service. In this broad sense, they can be described as tools. However, they are not tools in the classic sense of seamlessly extending the user's capabilities in a manner where the user attends to the task rather than to the vacuum cleaner. On the contrary, robotic vacuum cleaners aim to free the user from attending to the vacuuming task. They aim to be agents acting on the user's behalf in an autonomous manner. It is by displaying autonomy and agency that robotic vacuum cleaners have become a much-noted example of home automation (Carames et al., 2021). In contrast to virtual assistants such as Apple's Siri and Amazon's Alexa, robotic vacuum cleaners automate a mundane task that does not involve elaborate social interaction. They deemphasize interaction to the extent that they automate vacuuming as much as possible and merely leave the residual elements to the human user. Like in many products designed from a system perspective, these residual elements are mainly the dreary ones of maintaining the vacuum cleaner.

The transformation of the vacuuming UX involves its pragmatic qualities as well as its hedonic qualities. The pragmatic qualities are transformed by making it largely effort-free to vacuum more, thereby shifting the cost-benefit relation of vacuuming. Robotic vacuum cleaners are used for many more minutes a week than other vacuum cleaners. The increase is about sevenfold (Table 4). That is, robotic vacuum cleaners are not simply another appliance for performing the same task; they change the criteria that define the vacuuming task by escalating people's standards of cleanliness. The change resembles how text-processing systems escalated the standards of document formatting and increased the number of document edits compared to documents that were handwritten and then typed up (Landauer, 1995). The finding of increased vacuum-cleaner use with robotic vacuum cleaners accords with Nicholls and Strengers (2019). It also means that the accompanying changes in general housekeeping practices, such as keeping the floors free of obstacles, are frequently reinforced. With respect to new criteria for defining the vacuuming task, Wellendorf et al. (2022) found that some participants used the robotic vacuum cleaner to establish whether the floors were clean: The floors were considered clean when, and only when, the dust container was completely empty after the robotic vacuum cleaner had vacuumed them. In addition, robotic vacuum cleaners redefine the vacuuming task by making the residual maintenance activities relatively more salient to the user. For the user, vacuuming increasingly becomes a matter of keeping the floors free of obstacles, emptying the dust container, and replacing filters; the vacuuming itself recedes into the background because it is automated. This finding is evident in the videos, which show the participants in an active servicing role during maintenance and a detached supervisory role during vacuuming. The supervisory role matches how Dörrenbächer et al. (2022) find that the relation between user and robot can be one of delegation.

The transformation of the vacuuming UX also involves its hedonic qualities. Robotic vacuum cleaners give rise to affective and anthropomorphic relations that are not seen with other vacuum cleaners. One participant noted that the robotic vacuum cleaner was part of the family. In general, the participants experienced a higher proportion of hedonic stimulation quality with robotic (and upright cordless) vacuum cleaners (Table 9). This finding accords with previous studies, which frequently report that users have affective relations with their robotic vacuum cleaners (e.g., Forlizzi, 2007; Sung et al., 2010; Wellendorf et al., 2022; Yapici et al., 2022). However, the present study adds further information that moderates this finding

in two ways: Pragmatic quality is mentioned considerably more often than hedonic qualities, and the experienced hedonic stimulation quality is often negative rather than positive (e.g., "Unpleasant" rather than "Pleasant"). The moderated finding calls to mind that hedonic qualities were once distinguished from pragmatic quality by defining them as "task-unrelated qualities" (Hassenzahl et al., 2001). That is, they were defined by being alterity relations (Ihde, 1990). The affective and anthropomorphic relations people have with their robotic vacuum cleaners are largely task-unrelated alterity relations. For example, Yapici et al. (2022) quote a study participant for saying: "I would rather have a chat with a smart and autonomous robovac [i.e., robotic vacuum cleaner] than a smart fridge". Similarly, Scott et al. (2023) find that more than half of their participants perceived some degree of consciousness in robotic vacuum cleaners. In parallel with the task-unrelated hedonic qualities, the participants in the present study are not happy with the task-related pragmatic quality of their robotic vacuum cleaners.

Task-unrelated hedonic qualities are a different way of improving UX than the proposal by Klapperich et al. (2020) to keep the user engaged in the meaningful elements of the task. Focusing on the meaningful task elements is a task-related approach. By being task-unrelated, the users' affective and anthropomorphic relations to their robotic vacuum cleaners are not driven by pragmatic considerations such as ease, effectiveness, and efficiency; instead, they are orthogonal considerations about goodness, pleasantness, aesthetics, and the like (Table 10). Sometimes, task-unrelated qualities are at odds with the task-related ones. For example, Wellendorf et al. (2022) find that robotic vacuum cleaners appear more relatable and less threatening because their way of bumping into objects and getting stuck when they move around makes them charmingly clumsy. Søraa and Fostervold (2021) come to the same conclusion about service robots at a hospital. That is, technical imperfections and inefficiencies that detract from the pragmatic quality of the robots at the same time add to their hedonic qualities.

5.2 Inferior pragmatic quality

Robotic vacuum cleaners transform vacuuming even though they do a poorer job than the other vacuum cleaners. This disconnect between transformative power and pragmatic quality shows that factors other than pragmatic quality may be instrumental to UX, even for a mundane household appliance. The inferior pragmatic quality of robotic vacuum cleaners is evident in three ways.

First, robotic vacuum cleaners perform worse or not at all on seven out of nine surfaces (Table 7). It is evident that robotic vacuum cleaners are designed for a narrower range of tasks and, for example, cannot vacuum ceilings and stairs. However, they also underperform on several floor types, including hard floors. This underperformance concerns the principal function of robotic vacuum cleaners. In addition to these task-specific limitations, robotic vacuum cleaners are no better than other vacuum cleaners on feature-specific issues such as the experienced noise level (Table 8). For example, the noise level prevented the participants in the study by Fink et al. (2013) from sleeping upstairs while their robotic vacuum cleaner was vacuuming downstairs, thereby reducing their activity options during the freed time.

Second, robotic vacuum cleaners are not experienced as easier to use than other vacuum cleaners (Table 5). This finding may appear surprising because robotic vacuum cleaners largely automate use (but not storing and maintenance). The finding suggests that the automated elements of vacuuming recede into the background, thereby making the remaining manual elements more salient to the user. Such an effect is consistent with Klapperich et al. (2020), though their focus is on deliberately making meaningful elements more salient, rather than on inadvertently making residual elements more salient. The upright cordless vacuum cleaners do not render vacuuming an automated background activity. Instead, their lightness and cordlessness remain salient to the user during vacuuming and may explain why this vacuum-cleaner type is experienced as easier to use than the types canister with bag and without bag (Table 5).

Third, the participants with a robotic vacuum cleaner have at least one other vacuum cleaner, and they prefer their other vacuum cleaner(s) over the robotic one. The problems mentioned above, and those listed by

Honig et al. (2020), may help explain this preference against robotic vacuum cleaners. Furthermore, the participants' general happiness with their robotic vacuum cleaner is close to the neutral midpoint of the scale (Table 5). This finding corresponds with the notion of ordinary UX (Clemmensen et al., 2020; Meneweger et al., 2018), which has hitherto been confined to UX studies conducted in work settings. Vacuuming has similarities with routine work in that it is a chore that changes little from one instance to the next, merely has a temporary effect, and therefore must be performed regularly. This finding shows that ordinary UX can coexist with affective human-robot relations because the former may refer to pragmatic qualities while the latter refers to hedonic qualities.

5.3 Implications

This study has implications for robotic vacuum cleaners and household automation more generally. Five implications appear especially relevant to UX:

- Robotic vacuum cleaners transform vacuuming by reducing the user's involvement in the actual vacuuming and, thereby, make the residual maintenance activities relatively more salient to the user. They may also lead to escalated standards of cleanliness. Will the net result be saved time for the user? Are the escalated standards of cleanliness experienced as a cost-benefit improvement in UX?
- In contrast to much UX research, this study is about routinized use. It finds that the vacuuming UX contains contradictions that persist over time, thereby suggesting a more complex pattern than novelty effects that then wear off. How, if at all, do users reconcile the contradictions? Do the temporal dynamics between pragmatic and hedonic qualities follow recurrent patterns in the evolution of UX?
- During routinized use, robotic vacuum cleaners are poorer at vacuuming but better at sparking hedonic stimulation and anthropomorphism. However, the long-term consequences of these findings remain inadequately understood. Do users take better care of hedonically stimulating technologies? Is repair more likely than replacement for technologies that invite anthropomorphic relations?
- In working with the hedonic dimensions of UX, designers may target task-related qualities by involving the user in the meaningful elements of the task or task-unrelated qualities by inviting affective and anthropomorphic relations with the technology. The two approaches are quite different. Under what circumstances should designers choose one over the other? When and how may they be combined?
- The coffee maker by Klapperich et al. (2020) keeps the human in the loop for experiential reasons. Self-driving cars do it for safety reasons. Social robots do it because interaction with the user is their defining characteristic. Service robots, such as robotic vacuum cleaners, may be different. What, if any, are the meaningful elements of the vacuuming process in which users would appreciate to remain involved? Is the process, as opposed to its outcome, relevant to UX if users can and prefer to be left out of it?

These implications and questions call for future work. Whereas existing studies mainly investigate how users experience contemporary robotic vacuum cleaners, future studies may attend more to the design space available for engineering the vacuuming UX. To structure the data collection, researchers may for example consider the Godspeed instrument for measuring anthropomorphism (Bartneck et al., 2009) and the day reconstruction method for making longitudinal studies (Kahneman et al., 2004).

5.4 Limitations

Four limitations should be remembered in interpreting the results of this study. First, the study is comparative and therefore addresses questions that can be asked for all four types of vacuum cleaner. Questions specific to certain types are excluded but may capture issues important to householders' experience of those vacuum-cleaner types. For studies of issues specific to robotic vacuum cleaners, the reader is referred to related work (see Section 2.3). Second, the sample size of the study is modest. Thus, it cannot be ruled out that some differences among vacuum-cleaner types remained nonsignificant because the sample size was

insufficient to reveal them. Future work should validate and extend the findings of this study on larger samples, with different methods, and in cultural contexts other than Western Europe. Third, the three factors in the AttrakDiff model were not introduced as categories until the data analysis. The diaries would have been more structured in their overage of hedonic quality if they had included the standard questionnaire for measuring the three AttrakDiff factors (Hassenzahl, 2004). However, ICRT preferred tailor-made questions over standard question batteries when they devised the diaries. Fourth, the brands and models of the participants' vacuum cleaners are unknown. Specifically, some of them are not the newest model because the study investigates routinized rather than early use. Differences among models may mostly be an issue for robotic vacuum cleaners, which have evolved considerably in recent years and probably become outmoded more quickly than the other types of vacuum cleaner.

6 Conclusion

This study finds that robotic vacuum cleaners are inferior, yet transformative. They are inferior in pragmatic vacuuming qualities compared to other vacuum cleaners. At the same time, they transform vacuuming in four ways. First, they shift the cost-benefit relation of vacuuming by making it largely effort-free to vacuum more. Second, they lead to more frequent vacuuming, which suggests escalated standards of cleanliness. Third, they make the residual maintenance activities relatively more salient to the user. Fourth, they give rise to affective and anthropomorphic relations that are not seen with other vacuum-cleaner types. The transformative power of robotic vacuum cleaners relates to their autonomy and agency. These characteristics make hedonic stimulation more prominent in householders' vacuuming UX and have made robotic vacuum cleaners a much-noted example of home automation. The persistent interest in robotic vacuum cleaners despite their inferior pragmatic vacuuming qualities suggests that they may still mainly be for early adopters, who willingly accept that new technologies come with some problems and annoyances. Further research is needed to establish how the pragmatic, hedonic, and transformative qualities of home automation will combine into practices that reform the UX of household chores.

Declaration of competing interests

This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The data analyzed in this study were collected by International Consumer Research and Testing (ICRT), which in this specific case comprised the consumer associations Altroconsumo Edizioni SRL in Italy, Association des Consommateurs Test-Achats SC in Belgium, Consumentenbond in the Netherlands, DECO-Proteste Editores LDA in Portugal, OCU-Ediciones SA in Spain, and UFC - Que Choisir in France. ICRT subsequently made the data available to the author. The author is grateful to Niels Ebbe Jacobsen from ICRT for his support in making the data available for this study, to Design Psychology for administering the diary study, and to the participants for sharing their experiences with vacuum cleaners.

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