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A design evaluation tool for older adults using domestic information processing appliances

Abstract

Domestic information processing appliances include embedded digital technologies with which users interact. The designs of such appliances tend to be technology oriented and not well-suited to the needs of older adults. This is problematic because these appliances are essential in many activities of daily living and so affect the ability of people to live independently. This paper introduces a coding scheme for the analysis of users' interactions with such appliances and uses it to inform recommendations for the design of operational interfaces and associated instructional materials. The efficacy of the coding scheme as a design evaluation tool is illustrated by its application in a microwave oven case study. The coding scheme considers four aspects of users' interactions with this type of device: information processing activities, including the gathering and interpretation of information from the appliance, its user manual and cooking instructions from food packaging; interactions with the device's user interface; concurrent verbalisation supporting problem-solving; and impediments to the user's workflow.

Keywords:

Human-machine interface; user-centred design; independent living; domestic information appliance; elderly people.

1 Introduction

The importance of digital inclusion and so older adults being able to use digital interfaces for products and services is widely recognised. For example, Munteau et al. (2018) and Bradley et al. (2021) highlight the impact of service accessibility on digital inclusion in financial and transport systems, and so on older adults' social inclusion and well-being. Further, they and others argue that digital inclusion could be increased through the design of more inclusive digital interfaces (Sin et al., 2021). To this end, a new generation of interface design tools is emerging: driven by an underlying need for digital interfaces to be designed in the context of users' digital capabilities (e.g., see Ning et al., 2019 and Sin et al., 2021). While the majority of such design tools are related to the design of digital services, there is some work on the design of 3D products. For example, Goodman-Deane et al. (2020) propose a model for the design of interfaces to digital products that take account of the demands a product's interface places on users and the characteristics of such users. The focus of this paper is on the design of domestic information processing appliances (from here on referred to as "appliances") such as ovens and washing machines.

Older adults rely on appliances in their homes to maintain their independence. For example, Hunter (2016) reports that older adults living independently in their homes rely on appliances such as cookers and microwave ovens to meet their nutritional needs. However, such appliances tend to be technology oriented and not well suited to the needs of older users. For example, Wilkinson and de Angeli (2014) conclude that many of the features of cookers and microwave ovens remain inaccessible to many older adults. The Lifelong Kitchens (2016) project defined visible features and characteristics that could improve older adults' interactions with appliances. Other studies have produced information and advice on aspects of appliances

that were of value to older users (Kawamoto et al., 2014). For example, Kawamoto et al.'s study provided an understanding of older adults' requirements for kitchen design and adapted kitchen equipment and explored requirements for future products and systems that are sensitive to older adults' changing needs as they age. In contrast, this paper responds to the need, put forward by Bharucha et al. (2009), for an increased understanding of how older adults respond to the physical and cognitive demands of current appliances. Heiniö et al. (2017) argue that, for older adults living independently, improved ready-meal packaging may contribute to adequate nutritional intake. In turn, improved diet and health facilitate longevity and Heiniö et al. provide recommendations for the design of ready-meal packaging information.

Jones and Sarter (2008) suggest that two issues, poor feedback and the complex arrangement of features on interfaces, are major causes of older adults experiencing difficulties when using appliances. Both issues cause breakdowns in human-machine interaction. Maguire et al. (2014) report the results of several empirical studies that have identified ergonomic problems having a negative effect on users and their use of appliances. In the design of appliances, Mugge and Schoormans (2012) argue that perceptions of the level of novelty of appliances tend to be based on changes in their physical appearances, e.g., colour or shape, rather than features that improve usability. Insights from theories of technostress in older adults induced by information and communications technology use and cognitive ageing suggest that older adults are particularly susceptible to the negative consequences of interruptions and disruptions when using smart digital appliances and devices (Tams et al., 2018; Tams et al., 2020). The study reported in this paper is part of a wider research activity whose goal is to improve older adults' ability to live independently for longer by ensuring that the design of consumer appliances and associated materials support effective user-machine interactions. To this end, the study examined whether, how, and why ready meal packaging and appliance user interfaces lead to interruptions and distractions that impact task performance for older adults.

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The study identified factors associated with the design of instructional materials (both on appliance interfaces and in ready-meal packaging) that worsen user interaction and users' abilities to complete everyday tasks. While detailed issues related to the design of user interfaces are important, we found that there are also benefits in taking wider, system-level views of users' interactions with appliances, including the goal of the user's task and other resources that are used. For example, heating a ready meal typically requires user interaction with one appliance interface and two sets of instructions: the user manual for the appliance and cooking instructions for the ready meal. To support the design of new appliances that are easier for more people to use, there is a need for new, more holistic, design evaluation tools that support designers in taking system-level perspectives that put the appliance into its context of use. Expanding on Goodman-Deane et al's (2020) adaptation of the demand and exclusion model, this paper makes two key contributions: (i) a coding scheme for the analysis of users' interactions with appliances that could form the basis of future, more holistic, design evaluation tools; and (ii) guidelines for its use in the design of digital interfaces that take a systems perspective including the user, the appliance (including its interface) and instructional materials for the appliance (e.g., user manuals) and associated products such as washing instructions for clothing and cooking instructions for food.

2 Method

The research brought together descriptive and experimental research methods. Key stages in the overall research process are summarised in **Figure 1**. This paper reports findings from Stages 2 and 3. Results from Stage 1 are reported in Morris et al. (2014) and the reporting of Stage 4 is planned for a future paper. The remainder of this section provides details of the methods used in Stages 2 and 3, with results reported in Section 4.

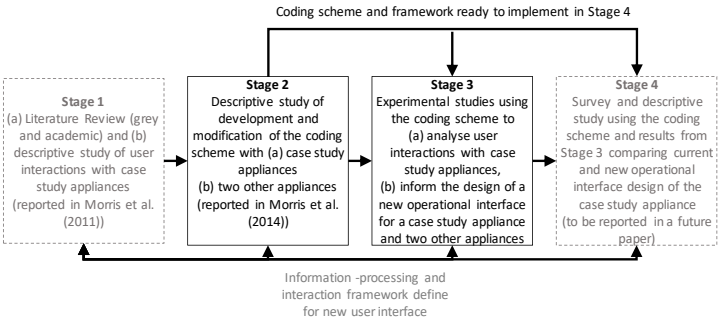

Figure 1: Key stages in the research methodology (reported in Morris et al., 2014)

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2.1 Stage 2: Descriptive study and development of the coding scheme

Learning from Stage 1 highlighted three aspects of appliance interfaces that influence users' interactions and so their ability to use them effectively to complete everyday tasks: physical features (such as the overall layout of the interface); handling features (such as switches, buttons, and control knobs); and visual features (such as text, symbols, images, icons, and lettering). The layout and visual features of instructional materials, such as user manuals for appliances and cooking instructions on food packaging, were also factors that influenced the effective use of such appliances, e.g. when heating a ready meal.

Given the purpose of the research, to support improved appliance design and so independent living of older adults, it was important to measure the efficacy of older users' interactions in ways that allowed the identification of relationships between interface features, over which designers have control, and older users' actions, which determine effective use. Morris et al. (2014) identified five features of users' interactions with appliances that influence their ability to successfully complete a given task. These were time spent processing information from (a) the appliance, (b) the appliance's user manual, and (c) instructions associated with the meal being cooked; and time spent operating the appliance: both in (d) making decisions related to the sequencing of activities and (e) managing multiple information processing and interaction activities. **Table 1** provides a summary of how these interaction features relate to the characteristics of appliances.

Table 1: Relationships between older adult users' activities, ready meal packaging, and appliance characteristics.

Relationships between older adult users' ready meal packaging and appliance	**Characteristics of appliances**		
	Physical	**Handling**	**Visual**
Information processing activities			✓
Interaction activities	✓	✓	
Dealing with impediments to workflow	✓	✓	✓
Time spent in multiple information processing activities			✓
Time spent in multiple interactions	✓	✓	

These informed the design and development of the coding scheme that used an iterative process involving a series of descriptive studies with five participants carrying out two activities: using a microwave oven to heat a ready meal or a washing machine to launder clothes. In each iteration, the coding interval used was reduced (from 10s through 5s and 2s to 1s) until no new codes were identified and differences in the coding compared with the previous phase were minimal. When new codes were identified the scheme was refined accordingly. The process ended after four iterations when no new codes were identified and differences in the coding using the finer intervals made little or no difference to the analysis results. Insights gained and the scheme itself is introduced in Section 3. The codes were then confirmed by a second coder who used the coding scheme to code 2s intervals of video. Across the two coders, key codes aligned. However, the second coder identified more cognitive domain events such as information gathering on the packaging, information gathering on information appliances, concurrent verbalisation supporting problem-solving, and, finally, searching for information.

2.2 Stage 3: Experimental studies using the coding scheme to analyse user interactions with case study appliances

The efficacy of the coding scheme as a design evaluation tool was assessed through a series of experiments where it was used to analyse four older adults' interactions with a microwave oven to heat a ready meal.

2.2.1 Participants

The purpose of this study was to assess the efficacy of the coding scheme as a design evaluation tool. For this reason, the participants were selected as representatives of the target users for the design process but there was no need for them to be representatives of the population as a whole. They were volunteers, drawn from a population that corresponded to the characteristics of age-related cognitive decline of interest in the research; inclusion criteria were that they were living independently and had sufficient mobility to act as carers for partners. There were no explicit exclusion criteria but they did need to attend a workshop to which they had been invited. **Table 2** provides a summary of the participants in Stage 3 of the research. All participants were white females who participated in a one-off workshop where they discussed their experiences and perceptions of appliance design. No men volunteered to participate.

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Table 2: Case study participants and their ages.

Participant	Age (years)
AD	68
JB	72
ST	74
DH	67

2.2.2 Procedure

As each participant arrived, the researcher gave her a research pack, which included a pre-selected ready-meal package, a task specification that explained the purpose of the research and the research process, and a consent form. The researcher asked the participant to read the instructions on the ready meal packaging before providing her with the ready meal and asking her to heat it in the microwave oven. Participants had no familiarisation time with the appliance interface before they heated the meal. The information source materials offered were the ready meal package and appliance instruction manual on how to operate the microwave oven. Participants talked aloud as they interacted with the appliance, the ready-meal packaging, and associated instructions.

2.2.3 Research instruments

The research used three instruments: a microwave oven user interface (see **Figure 2**), M&S ready meal packaging instructions (participants selected from a choice of four meals: Roasted Butternut Squash Lasagne, Cod Mornay, Chicken and Vegetable Hot Pot, and Salmon with Soy and Ginger) (see **Figure 3**) and the microwave oven's printed user manual (see **Figure 4**).

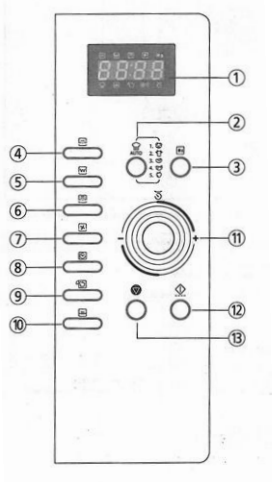
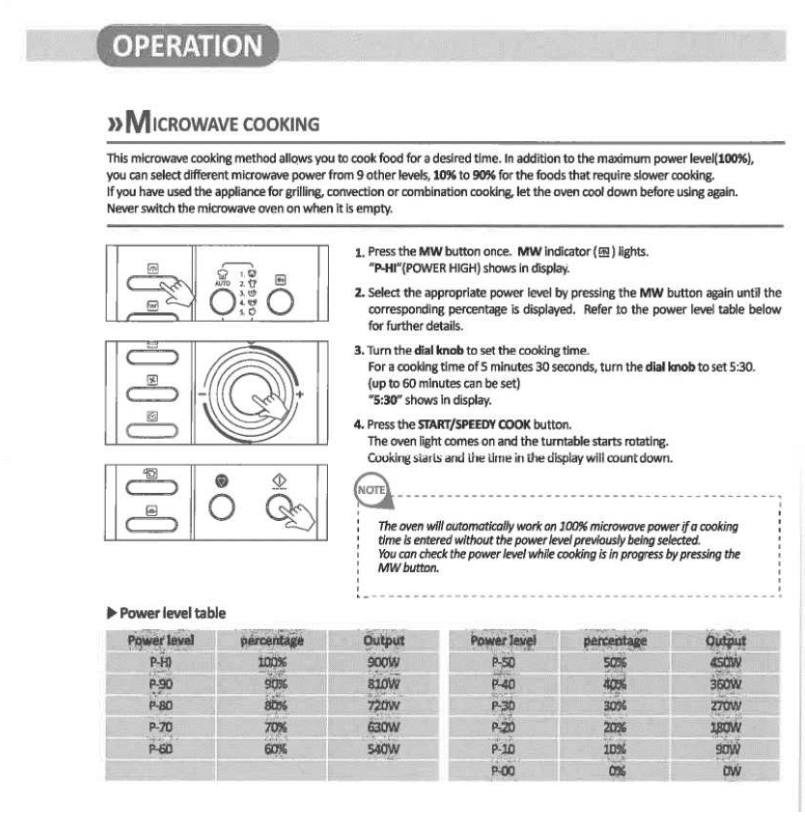


Figure 2: The microwave oven appliance interface MODEL NUMBER KOC-9Q3T / KOC-9Q3TC MICROWAVE CONVECTION/GRILL OVEN (Daewoo, 2015). Reproduced from use manual (1) Display: Cooking time, power level, programme indicators, and present time display. (2) Auto cook. (3) Defrost. (4) MW: Used to set the power level of the microwave. (5) Grill. (6) Combi: Used to select combination mode. (7) Convection: Used to select convection mode and selected temperature. (8) Clock. (9) Steam cleaning: Used to clean the inside of the oven. (10) Warm: Used to keep the food warm. (11) Dial Knob: Used to set time, weight, and quantity. (12) Start/Speed cook. (13) Stop/Clear: Used to stop the oven's operation or to delete the cooking data (Daewoo, 2013).

Figure 3: Net of a typical ready meal package and cooking instructions used in the study.



OPERATION

»MICROWAVE COOKING

This microwave cooking method allows you to cook food for a desired time. In addition to the maximum power level(**100%**), you can select different microwave power from 9 other levels, **10%** to **90%** for the foods that require slower cooking.
If you have used the appliance for grilling, convection or combination cooking, let the oven cool down before using again.
Never switch the microwave oven on when it is empty.

1. Press the **MW** button once. **MW** indicator ( ) lights.
   "**P-HI**"(POWER HIGH) shows in display.
2. Select the appropriate power level by pressing the **MW** button again until the corresponding percentage is displayed. Refer to the power level table below for further details.
3. Turn the **dial knob** to set the cooking time.
   For a cooking time of 5 minutes 30 seconds, turn the **dial knob** to set 5:30.
   (up to 60 minutes can be set)
   "**5:30**" shows in display.
4. Press the **START/SPEEDY COOK** button.
   The oven light comes on and the turntable starts rotating.
   Cooking starts and the time in the display will count down.

NOTE

The oven will automatically work on 100% microwave power if a cooking time is entered without the power level previously being selected.
You can check the power level while cooking is in progress by pressing the MW button.

▶ **Power level table**

Power level	percentage	Output	Power level	percentage	Output
P-HI	100%	900W	P-50	50%	450W
P-90	90%	810W	P-40	40%	360W
P-80	80%	720W	P-30	30%	270W
P-70	70%	630W	P-20	20%	180W
P-60	60%	540W	P-10	10%	90W
			P-00	0%	0W

Figure 4: The manual and trouble-shooter instructions. Reproduced from user manual (Daewoo, 2015).

2.2.4 Data collection

The participants were video recorded as they used the oven to heat the selected ready meal. Verbal and visual data interaction points were recorded using a digital audio recorder. The names of the participants were anonymised. This data was used to code each participant's use of the oven using the coding scheme introduced in Section 3.

2.2.5 Data analysis

The analysis used the coding scheme which covers 15 information processing activities, eight concurrent verbalisations supporting problem-solving, six interactions, and two impediments to workflow. The overall design of the research process is shown in **Figure 5**. The tasks were video recorded using methods described by Bødker (1995) and Suchman and Trigg (1991). The footage was analysed using verbal protocol analysis methods described by Ericsson and Simon (1998) to identify operational interface issues. The results are presented in the form of histograms to visualise the balance and distribution of interactive activities for each participant. For example, the breakdown of information processing acquisition behaviour can be used to see how balanced the interaction is, and the number of interaction breakdowns or focus shifts that impeded workflow provides insights into the distribution of values within a single code category.

In addition, an online consumer feedback forum about the specific microwave oven used in the study was surveyed to triangulate findings from the data analysis. Fourteen online consumer feedback responses about the appliance's usability were identified. Responses were selected if they related to operational interface issues with the microwave oven. Findings were used to derive evaluative performance criteria for the microwave oven. The coding scheme itself is introduced in Section 3 and results from Stage 3 are presented in Section 4.

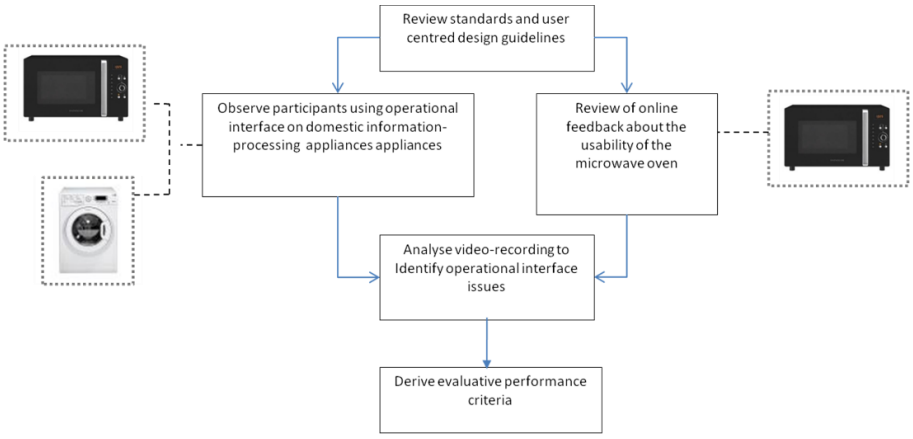


Figure 5: Process used to identify participants' interactions with appliances in Stages 2 and 3 (this paper only relates to the microwave oven)

3 Stage 2 results: The coding scheme

The coding scheme given in **Table 3** was first reported in Morris (2016) and has since been refined. It is based on Pheasant's (1986) body space model but adapted, as shown in **Figure 6**, to highlight proximity between actions and verbalisation when participants experience difficulties interacting with the ready meal instructions, display, and controls. The coding scheme itself includes codes in three categories of activity: information processing activities (including subcategories of concurrent verbalisation supporting problem-solving), interactions, and impediments to the workflow (interaction breakdown and interaction focus-shift). Each element of the coding scheme is an activity involved in the use of an appliance. In **Table 3**, each of these activities is assigned a number or letter for use when coding a user completing a given task, and a label for use in the traces (e.g., see **Figures 7-10).** A more detailed description of each code is provided in the Description column. The activities are related to key sources from the literature: Anderson et al.'s (2001) cognitive domains and the types of impediments to workflow identified by Winograd and Flores (1986). The final two columns show the types of data used when coding. For example, when identifying intentions (Code 1), both verbal and visual were used.

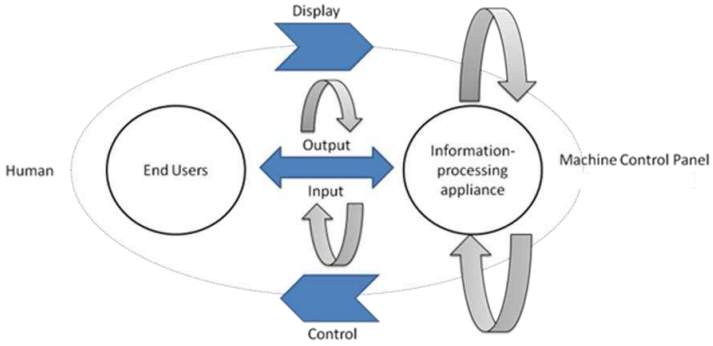


Figure 6: An illustration showing the information processing route driven by interaction between research instruments and participants (adapted from Pheasant, 1986).

Table 3*:* The coding scheme with information processing activity categories linked to concurrent verbalisation supporting problem-solving, interaction, and impediments to workflow activity. (Part 1 of 3)

Code	Label	Description	Cognitive domain	Type of data used	
				Verbal	Visual
Information Processing Activities					
1	Identifying intentions	Participant appears to be identifying basic intentions (e.g., to heat a ready meal) and recalling facts	Remembering	✓	✓
2	Information gathering: meal packaging	Information gathering from the meal packaging. For other activities, e.g., washing clothes, replace meal packaging with labels on clothing.	Analysing	✓	✓
3	Information gathering: appliance manual	Information gathering from the appliance manual.	Analysing	✓	✓
4	Information gathering: appliance user interface	Information gathering from the appliance user interface.	Analysing	✓	✓
5	Information obtained	Information obtained from meal packaging/ appliance manual/ appliance user interface	Understanding	✓	✓
6	Operational interface issue: appliance user interface	Operational interface problems identified on the information appliance user interface.	Analysing	✓	-
7	Operational interface issue: meal packaging	Operational interface problems identified in meal packaging. For other activities, e.g., washing clothes, replace meal packaging with labels on clothing.	Analysing	✓	-
8	Operational interface issue resolved	Operational interface problems on appliance user interface/ meal packaging resolved.	Creating	✓	✓
9	Irrelevant information identified: meal packaging	Irrelevant information from meal packaging was identified. For other activities, e.g., washing clothes, replace meal packaging with labels on clothing.	Analysing	✓	-
10	Irrelevant information identified: appliance user interface	Irrelevant information from the appliance operational interface was identified.	Analysing	✓	-
11	Cognition issue identified	Cognition problems/issues/challenges identified: referring to the mental processes involved in gaining knowledge and comprehension	Analysing	✓	✓
12	Cognition issue resolved	Cognition problems/issues/challenges resolved	Creating	✓	✓
13	Visual cognition issue identified	Visual cognition problems/issues/challenges identified: referring to interpreting the use of ready meal packaging and appliance characteristics as reflected by the objects in the information processing loop	Analysing	✓	
14	Visual cognition issue resolved	Visual cognition problems/issues/challenges resolved	Creating	✓	✓

Table 4*:* The coding scheme with information processing activity categories linked to concurrent verbalisation supporting problem-solving, interaction, and impediments to workflow activity. (Part 2 of 3)

Code	Label	Description	Cognitive domain	Type of data used	
				Verbal	Visual
15	***Concurrent verbalisation supporting problem-solving***	Step in explicit instruction and verbalisation to scaffold the learning of problem-solving and metacognitive strategies	Evaluating	✓	✓
15a	Packaging/appliance instructions/ appliance interface	Meal packaging/ appliance manual/ appliance user interface: examining and breaking information into parts	Evaluating	✓	✓
15b	Information from meal packaging/ appliance manual/interface	Information obtained from meal packaging/ appliance manual/ appliance user interface: translating and interpreting information	Evaluating	✓	✓
15c	Operational interface problem: inferring/finding visual elements	Operational interface problems: inferring and finding qualitative data of visual elements problems	Evaluating	✓	✓
15d	Operational interface problem: translating/interpreting visual elements	Operational interface problems: translating and interpreting visual elements and information problems	Evaluating	✓	✓
15e	Irrelevant operational interface information obtained	Irrelevant operational interface information obtained: examining visual elements and information to identify causes and effect	Evaluating	✓	✓
15f	Visual cognition problems/issues/challenges with interfaces identified	Visual cognition problems/issues/challenges with meal packaging/ appliance manual/ appliance user interface: breaking visual elements and information into parts by identifying causes and effect	Evaluating	✓	✓
15g	Visual cognition problems/issues/challenges with interfaces resolved	Visual cognition problem from meal packaging/ appliance manual/ appliance user interface resolving to compile information together in diverse ways by combining visual elements and new knowledge	Evaluating	✓	✓
15h	Verification of ideas to determine complexity from interfaces	Verification of ideas to determine the level of complexity from meal packaging/ appliance manual/ appliance user interface	Evaluating	✓	-

Table 5*:* The coding scheme with information processing activity categories linked to concurrent verbalisation supporting problem-solving, interaction, and impediments to workflow activity. (Part 3 of 3)

Code	Label	Description	Cognitive domain	Type of data used	
				Verbal	Visual
Interactions					
16	Searching for information: judgments on information & visual elements	Searching for information: presenting and defending opinions by making judgments about information and visual elements	Evaluating	-	✓
17	Categorising information from interface & manuals	Categorising information: combining visual elements and information in new patterns or proposing alternative procedural solutions	Creating	-	✓
18	Programming appliance	Programming: applying acquired knowledge, facts, techniques, and rules to the user interface	Applying	-	✓
19	Problem scoping: understanding of the procedural domain	Problem scoping: demonstrating an understanding of facts and ideas relating to the procedural domain	Understanding	-	✓
20	Checking content/equipment/utensils	Checking content/equipment/utensils	Evaluating	-	✓
21	Developing alternative solutions: planning operations	Developing alternative solutions with M/C: producing a plan or proposing a set of operations	Evaluating	-	✓
Impediments to a workflow activity					
A	Interaction breakdown: Discontinuity in the operational sequence	Interaction breakdown: Stop in the operational sequence (where the task was stalled)	Stop in workflow activity	-	✓
B	Interaction focus shift: Shift in user's attention/distraction from the task	Interaction focus shift: Shift in the operator's attention, the relocation to another operational interface feature (where a participant is distracted from the task)	Relocation to other workflow activities	-	✓

4 Stage 3 results: Experimental studies

The efficacy of the coding scheme as a design evaluation tool was assessed by applying it to the use (by four participants) of an appliance (a microwave oven) to heat a ready. Results from these evaluations are reported here. Conclusions and recommendations to inform the future design of a new operational interface for appliances are introduced in Section 5.

4.1 Data collection and analysis

Comparisons were made between participants' traces in **Figures 7-10**. Each trace uses a template with the information processing activities from **Tables 3-5** on the left-hand side and a timescale, in 2-second intervals, progressing from left to right. The coloured cells show the information processing activities being carried out by the participant in each interval; the colours reflect the groupings of activities in **Tables 3-5** and are intended to improve the readability of each chart. Finally, at the bottom of each chart, a histogram is provided that summarises the number of different types of information processing activity that were used in each interval. The length of each trace reflects the time taken to complete the task. For example, ST took 4 minutes whereas the other three participants each took less than 2 minutes to complete the task. It can be seen that, in each case, the participant's interactions covered the majority of codes though ST took significantly longer than the others to complete the task.

Figure 11 shows the interplay of packaging information features and user interface elements in the two loops shown in Figure 6. **Figure 11** shows regions of attention and focus on which concurrent verbalisation during the heating of the ready meal occurred. It can be seen that participants relied on interactions with the user interface and information on the packaging to navigate exchanges of information. The instructions used in cooking were focused on the visual characteristics of the appliance and ready meal packaging, specifically, cooking temperature, duration time, and heating thresholds.

It can be seen from the traces and **Figure 11** that interaction breakdowns and focus shifts were key issues faced by two participants (JB and DH). **Figure 11** suggests that the instructional information, display, and controls on the appliance did not drive a compelling narrative that facilitated their decision-making. Furthermore, the size of visual instructions on both the appliance and meal packaging was too small for them to read easily. All participants identified difficulties in creating meaning from the information provided. In addition, direct manipulation of controls on the appliance did not result in feedback (e.g., tactile or visual) to indicate that appliance had responded to the user input.

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Figure 7: A trace of ST use of the microwave oven to heat a ready meal, including a chart of multiple interactions and information-processing activities.

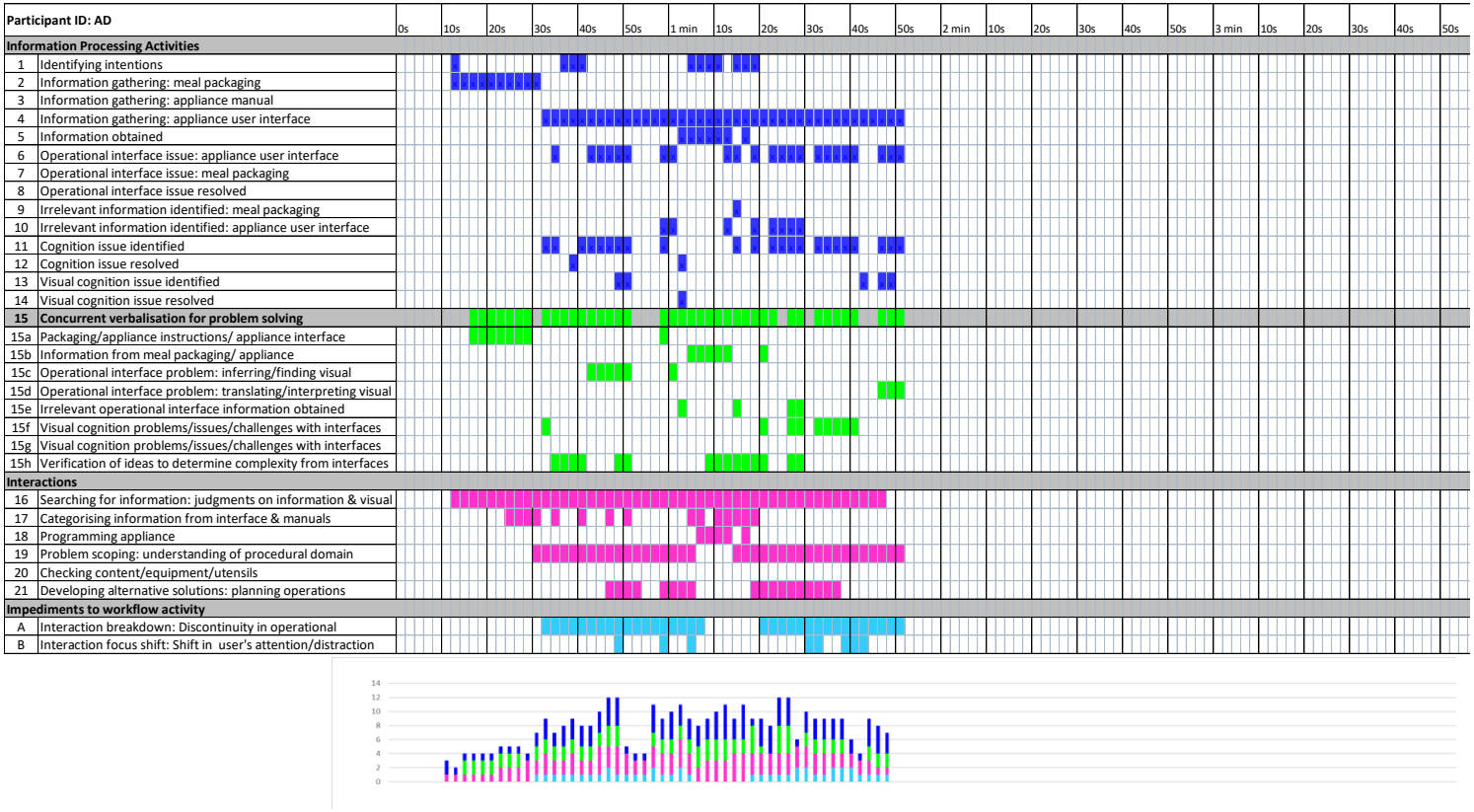

Figure 8: A trace of AD use of the microwave oven to heat a ready meal, including a chart of multiple and overlapping interactions and information-processing activities.

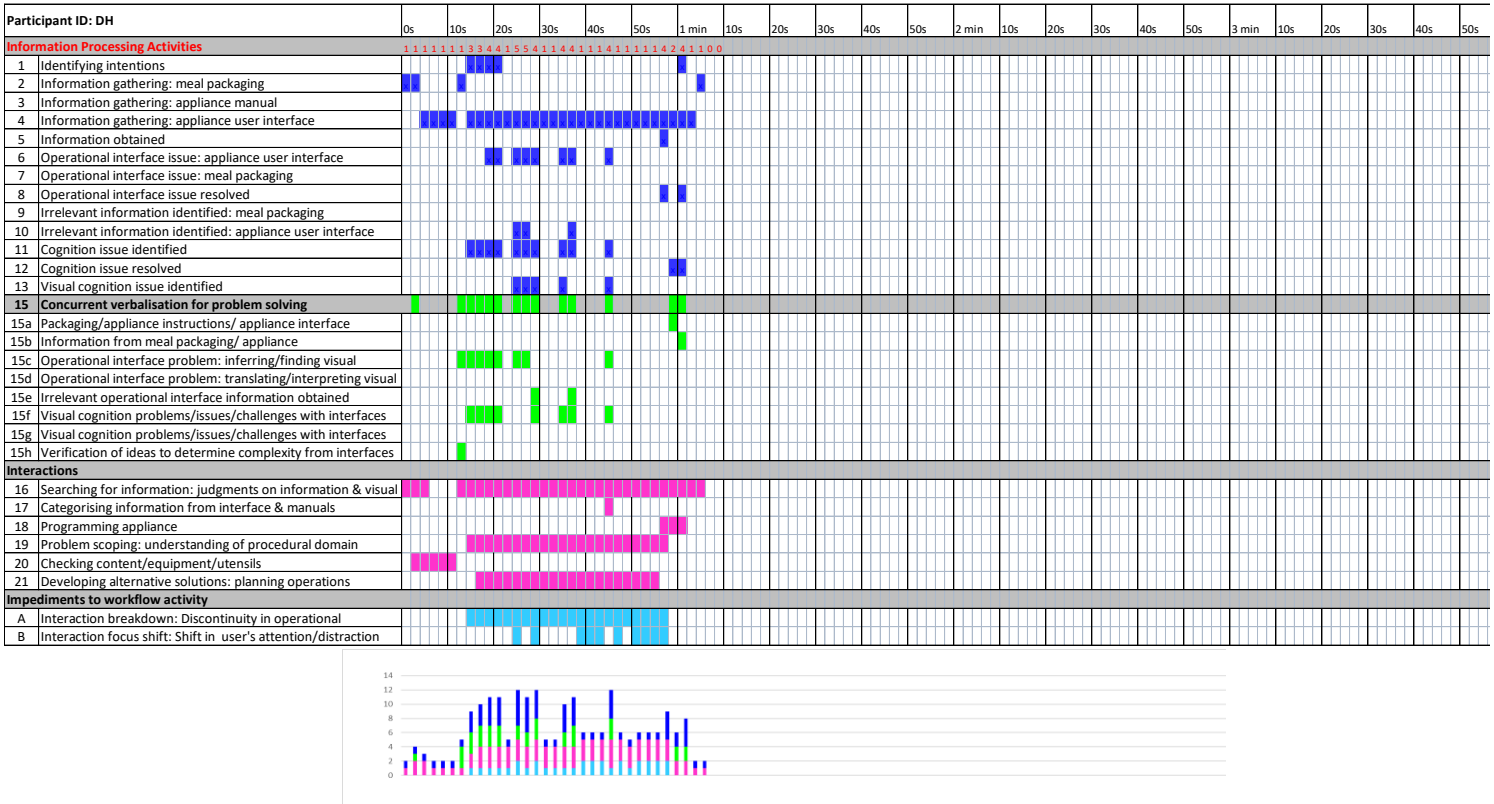

Figure 9:A trace of DH's use of the microwave oven to heat a ready meal, including a chart of multiple and overlapping interactions and information-processing activities.

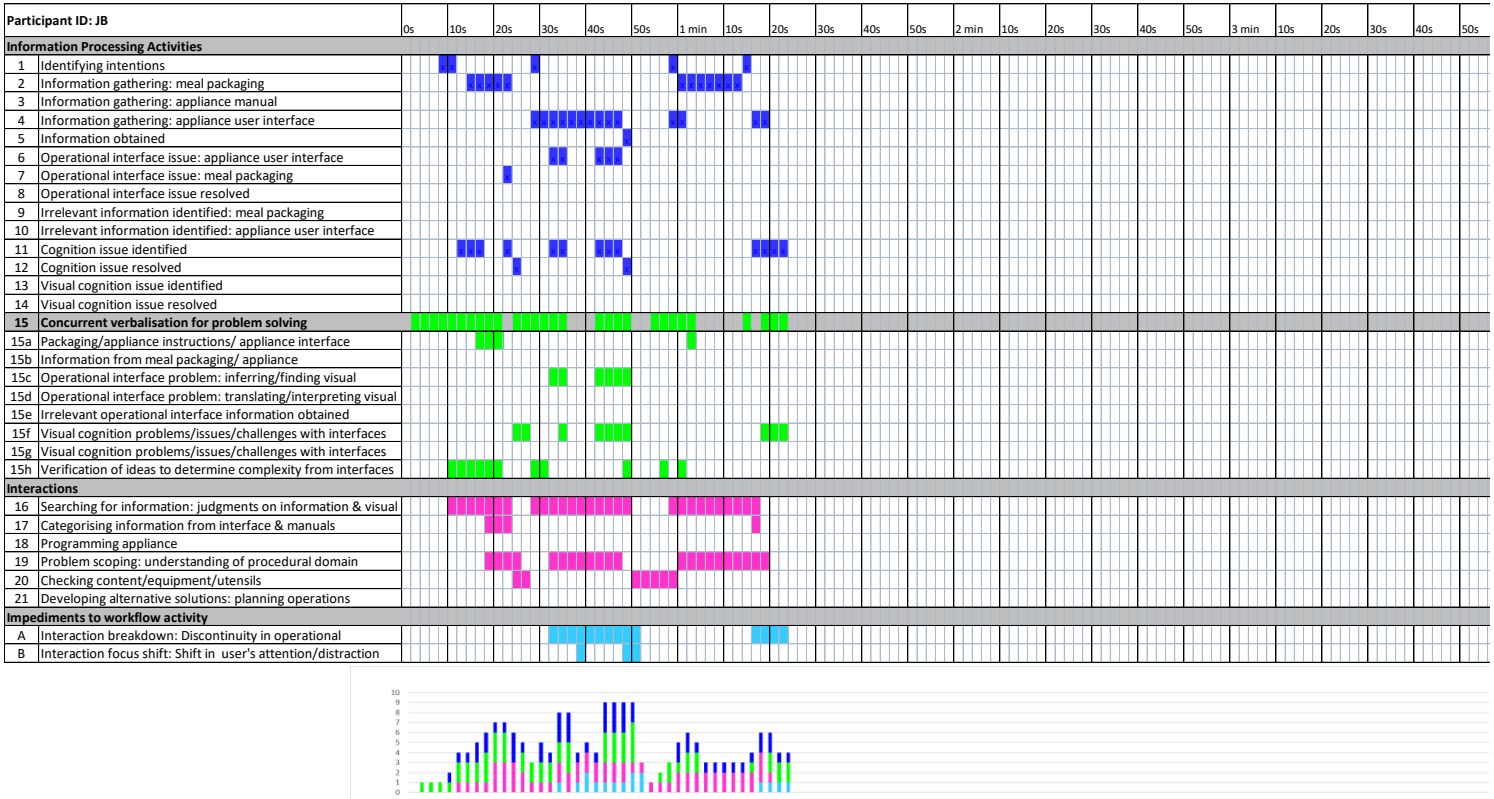

Figure 10: Trace of JB's use of the microwave oven to heat a ready meal, including a chart of multiple and overlapping interactions and information-processing activities.

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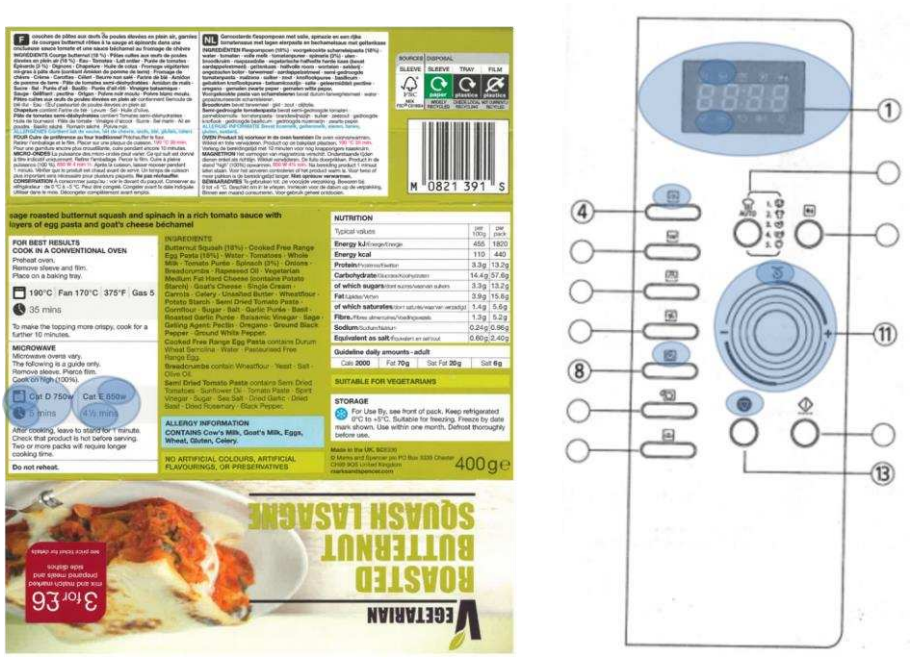

Figure 11: Dominant interactions on the appliance user interface and meal packaging. The blue circles show areas of interest and the deeper colours show areas of focus.

General patterns of tactile interaction with the appliance were unevenly distributed, and information differed in syntax, logic and semantics between the packaging and appliance. Primary visual areas, such as beginning points and terminal points, were not prominent on the appliance, resulting in a lack of guidance on sequencing options and important visual areas receiving limited attention from participants. Results suggested that JB and DH experienced difficulties when attempting to make connections between the ready meal packaging and the appliance because the information resources used were inconsistent with each other and did not reflect the sequential process or activities involved in heating a meal in a real-world context. As a result, cognitive demands were high and exacerbated by actions needed to manage information breakdowns and focus shifts. In turn, JB and DH's ability to resolve problems was influenced more by relevant information on the meal packaging than information on the appliance and its user interface.

The results show consequences of complexities in the visual stimuli on the user interface, ready meal packaging, and information source materials. Specifically, the distractor stimuli on the ready meal packaging and appliance affected older users' attention levels. Overlapping information-processing activities and interactions were aspects of operational procedure. Information-processing activity codes of analysing and evaluating were key domains of action, activities and operations. In addition, interaction codes of evaluation were consistent and high.

Overall, the findings indicate that the four participants used process-specific lateral interactions in the task to attempt to align information sources, for example, when there were inconsistencies between cooking instructions on food packaging and the appliance (**see Figure 11**). In line with Old and Naveh-Benjamin (2008 and 2012), most interaction breakdowns and focus shifts coincided with visual information elements on the appliance.

4.2 Triangulation of results

The results were triangulated using consumer comments from an online forum. Fourteen reviews of the microwave oven used in this study were selected because they referred to aspects of the user interface. Key points related to the functional and sequential grouping of interface elements. With respect to functional grouping, from the observations, users experienced impediments to workflow and interaction breakdowns and focus shifts when the ordering of operational interface elements did not reflect the operational sequence of the task, and when these elements were not grouped logically from a user perspective. These were used as drivers for the recommendations for the design of operational interfaces and instructional materials that are introduced in Section 5.

Commented [AM6]: Response to 2.3 (Part 2/2)

4.3 Reflection on the coding scheme from Stage 2

The coding scheme introduced in Section 2.1 enables the analysis of relationships between interaction breakdowns, focus shifts, and visual information elements by making explicit participants' conscious and unconscious interactions and information-processing activities in the two interaction loops shown in Figure 6. The illustration in Figure 6 is used to represent the analysis of the human-machine loop. We illustrate the relationship between the older user and microwave oven operational user interface, without the use of information source material such as the ready-made meal instructions and appliance manual. Key features of these interactions included information-processing activities, operational procedures, time spent dealing with impediments to workflow activity, and overlapping transitions. Indeed, the participants tended to resolve difficulties they experienced by referring to information in an operational sequence. In this study, users' competencies in interaction and information processing aligned with perceptions identified by Higgins and Glasgow (2012). Further, the nature of these competencies in a task-specific information-processing context has been established: indicating that analysing, evaluating, understanding, and remembering are four competencies of information-processing activities, and analysing, evaluating, applying, and creating are proficiencies of interactions.

Figure 11 shows two critical aspects of the system design through the grey arrows: (1) controls and displays used in the human-machine loop and (2) information source materials used in the information-interaction loop. A benefit of the coding scheme is that it highlights ways in which these two loops influence each other. The information-processing route, driven by the interaction and information-processing codes, shows that multiple processes are completed before the next activity with the appliance starts. Inconsistencies between information from various sources, e.g., the user interface on appliances, and in manuals, labels, and packaging, have a significant impact on older users' abilities to complete essential activities of daily living. These inconsistencies reveal that many processes involved in cognitive tasks occur concurrently (for example, see the traces in **Figures 7-10**).

Overlapping information-processing activities and interactions were found to be key to the effective use of the appliance. Evaluations of the participants' information-processing activities revealed that talking (understanding and evaluating) was an important aspect of their information processing. Qualitative data (from fourteen respondents to an online survey via Amazon's customer reviews of the appliance model) show the importance of sequence recognition, low-order cognitive skills and functional-level language used in concurrent verbalisation supporting problem-solving), which was used to rehearse and reiterate intentions. This suggests that the older user's knowledge of the task in a real-world context supports interactions and information-processing activities. Of particular interest was the fact that the coding scheme could be used to make explicit the order and sequence of older users' conscious and unconscious interactions and information processing. Qualitative data highlighted effective cognitive learning, including the development of alternative action plans through analysis and evaluation of interaction breakdowns. For example, the time each participant spent in interactions and operational procedures was key to explaining why the four participants focused heavily on task-specific information, e.g., spending time translating task-relevant and irrelevant information on the ready meal packaging and the appliance user interface.

5 Discussion

Commented [AM7]: Edits made to respond to 1.3, 1.5, 2.4, 2.6 & 2.7

Commented [AM8]: Response to 2.2

In line with the overarching goal of this research, the importance of designing technology-based products that are usable by older adults to complete activities of daily living is widely recognised (Rogers, et al. (2020) and a number of researchers propose tools for delivering such designs. For example, Goodman-Deane et al. (2021) provide a series of personas for older adults using digital, often mobile, interfaces to transport systems in Europe. In contrast, the research reported in this paper was motivated by current, negative, experiences of older adults using appliances within the home. In these situations, older users need to employ strategies that relate to task-specific information processing. The research resulted in a coding scheme for analysing the use of an appliance (through its user interface) and instructional materials (an appliance manual, and instructions on ready-meal packaging) to build an understanding of how older users used a microwave oven in an activity of daily living. Results highlighted a need for integration of information on the appliance, its user manual, and cooking instructions on ready meal packaging. For example, discrepancies between the sequencing of activities in cooking instructions and the positioning of interface elements on the appliance were found to be the root cause of interruptions to users' workflows.

The online survey data suggest that respondents were concerned about the microwave oven user interface. Their concerns may be attributable to respondents' perceptions that they had selected and used irrelevant text, icons, labels, symbols, digital displays, control buttons, and knobs to support programme selection. In this study participants were unable to identify key features and visual concepts that underpinned the procedures involved in heating food in the microwave oven. Furthermore, they were unable to justify and substantiate their final choice of the user interface as honest reflections of their intended operational procedures because the user interface did not relate to the processes, ideas, and practical tasks involved in heating, defrosting, cooking, roasting, and grilling food in the microwave oven.

In this study, participants reported on the information on meal packaging. Key information was knowing how much time was required to cook and the appropriate power setting. However, most experienced difficulties in identifying and selecting the text, icons, tables, symbols, digital displays, control buttons and knobs to support or identify and translate

to time and power selection. A lack of awareness was expressed regarding appropriate power settings. The most significant finding was that participants acknowledged the information on the microwave oven and meal packaging did not align. In addition, it was not at the appropriate size or contrast for reading, therefore, programming the microwave oven was difficult. Participants examined problems and issues with the user interface from a user's perspective, continually referring to the level of interaction deficit and information processing affected. Most noticeably, the user interface did not relate to visual ideas and concepts found in previous microwave ovens.

The results suggest that older users do face technology challenges such as understanding the manipulation rules of input and output controls in the two processing loops. This requires cognitive processes demonstrated by older users. Maintenance of information, rehearsal, and elaborate rehearsal are evident, demonstrating through excessive concurrent verbalisation that the process requires reference to visual stimulus, visual triggers, and previous experiences and process knowledge.

To deliver better ready meal packaging information, appliances, and information source materials, which demonstrably support older people to remain active and independent, requires improvements in the quality of policy, legal and regulatory environments surrounding information design, packaging, and appliance design. In addition, an assessment of the communication, practices, human activity, and effective use of information resources is needed. For example, in this study, more effective information had the following characteristics:

- (1) **Feature consistency** – of meaning and actions relating to a given task (e.g., heating a ready meal).
- (2) **Procedural consistency** – in operational procedures (e.g., linked to a linear sequence of activities).
- (3) **Layout consistency** – in the positioning of elements of control panel features and information on meal packaging (e.g., logical grouping of elements).
- 4) **Symbolic semantic consistency** – in the style and appearance of signs, lettering, labels, and symbols used (e.g., observed on common user interface elements).

Poor organisation of information appears to be a powerful factor influencing older users' information processing and interactions. The participants employed a range of strategies relating to this specific information processing context. Information in two areas is considered ineffective: information continuum and information categories.

- **Continuum** refers to the grouping of information based on sequential grouping and logical steps (e.g., plug-in appliance, press, 'on' button…press 'start' button).
- **Categories** refer to the grouping of information by activity and a functional level language and its relatedness to the real-world process. People naturally seek information by categorising steps (e.g., cook, temperature, time, etc.).

The successful design and operation of user interface structures are dependent on understanding use conditions at points of interest. A user-capability approach defined by the significance of information would respond to requirements in both the information continuum and information categories.

Of more significance is that participants faced additional information challenges such as understanding the inconsistent figures, labels, lettering, text, signs, and symbols provided.

These are required to understand and influence activities, procedures, and operational sequence. In this context, we can interpret user-capability design to include the characteristics of the activities; task patterns; task activities, and the information resources such as manuals, appliance user interface, and ready meal packaging. Visual information and instructions on their own are not beneficial to understand information-processing activities. Noticeably, the overlapping transitions amongst information-processing activities and interactions demonstrate the older users' complex processing ability and their willingness to attempt different information-processing actions simultaneously.

On this basis, a need for guidelines to support more user-driven approaches for the design of appliances and associated instructional materials was identified in **Error! Reference source not found.**.

Table 6: User interface design recommendations to increase accessibility to appliances and ready meal packaging, appliance, and instructions.

	Recommendation	Design Requirement
1	Use purposeful language	Interface information should allow users to make meaningful connections between tasks, activities, and goals
2	Make the size and orientation of information suitable for reading	The text needs to be appropriate for target users. Make the size and orientation of information appropriate for reading. Ensure that users can read the information from a minimum distance of 500mm
3	Use consistent instructions and information on operational interfaces	Standardise interface elements
4	Use visual and auditory "responses" on operational interfaces	Ensure that user interfaces provide feedback to users
5	Use functional grouping in positioning interface elements	Place operational interface features in a logical operational series
6	Order interface elements to reflect the sequence of use	Place sequential interface features in a logical operational series
7	Use intuitive messages, symbols, and imagery to ease the learning curve of the product operation.	Learnability: necessary for appliances used on a regular basis
8	Allow participants to tailor actions, operational series, and activities	Flexible in Use: to accommodate the needs and capabilities of different users
9	Use recognisable and easily understood words, phrases, symbols, and imagery	Perceptibility & intelligibility: users need to be able to understand verbal and visual terminology without using supplementary information such as instruction manuals
10	Use sequential series and auditory repetition of words, phrases, symbols, and imagery to minimize cognitive overload	Minimise the level of cognitive effort necessary to complete a task and achieve goals
12	Use operational series and discriminate between operational interface features	Actionability: ensure users are aware of necessary actions to complete a task and achieve goals

6 Conclusion

Commented [AM9]: Edits made & restructured/elaborated to respond to 1.3, 1.5, 2.4, 2.6 & 2.7

In this paper we have proposed a coding scheme for evaluating current interfaces of domestic information processing appliances and demonstrated its efficacy as an interface evaluation tool by applying it to a design case study involving older adults' use of microwave ovens to heat a ready meal. Building on this, guidelines for the design of operational interfaces and associated information are provided. A key limitation of the study was the small number (four) participants and further developments of the coding scheme are likely to be identified with wider use. This, coupled with variations in the capabilities of older users (e.g., see Goodman-Deane et al. (2021b)), makes it inappropriate to draw general conclusions. On the other hand, as design tools, both the recommendations for the design of user interfaces and the coding scheme for evaluating design alternatives have the potential to provide designers with new insights. Further, if generalisations were to be made then the sampling process would need to take account of the whole user system (see Figure 6) and so include appropriate numbers of users, appliances and ready-meals.

An important benefit of the coding scheme and guidelines is the potential for improvements in the design of consumer appliances, primarily through interfaces targeted to the needs and capabilities of real users. Further benefits could be gained from using the scheme in information design, e.g., on instructions on ready meal packaging. Although there is limited published work on technostress for older adults (Nimrod, 2018), such interfaces have the potential to reduce technostress and the coding scheme could be used in further work to identify specific antecedents and consequences. As stated at the beginning of this paper, the overarching goal of this research is to improve older adults' ability to live independently for longer by improving the design of consumer appliances and associated instructional materials. With respect to frame innovation (Dorst, 2015), the coding scheme expands the boundary of the design problem by including, in addition to the appliance, users and their interactions with the appliance and other sources of information. This, in turn, opens new avenues for the development of consumer appliances, e.g., by exploiting technological developments to create new generations of appliances with adaptive interfaces and capability-based operational user interface designs that focus on the needs of smaller groups of target users and the operational procedures they are carrying out. In the longer term, we envision new generations of adaptive consumer systems that integrate appliances with instructional materials to better support users in specific tasks. For example, -to support the development of assistive technologies and associated instructional materials for people with disabilities, a similar design approach to the one introduced in this paper could be used but with a suitably adapted coding scheme, e.g., based on the disability user-capability design framework presented by Morris, et al (2022).

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7 Ethics

The University of Leeds ethics approval was granted for this research through application number MEEC 10-028.

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