HUMAN FACTORS OF UBIQUITOUS COMPUTING: AMBIENT CUEING IN THE DIGITAL KITCHEN?

By

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Abstract

This thesis is concerned with the uses of Ubiquitous Computing (UbiComp) in everyday domestic environments. The concept of UbiComp promises to shift computing away from the desktop into everyday objects and settings. It has the twin goals of providing 'transparent' technologies where the information has been thoroughly embedded into everyday activities and objects (thus making the computer invisible to the user) and also (and more importantly) of seamless integration of these technologies into the activities of their users. However, this raises the challenge of how best to support interaction with a 'transparent' or 'invisible' technology; if the technology is made visible, it will attract the user's attention to it and away from the task at hand, but if it is hidden, then how can the user cope with malfunctions or other problems in the technology?

We approach the design of Human-Computer Interaction in the ubiquitous environment through the use of ambient displays, i.e. the use of subtle cueing, embedded in the environment which is intended to guide human activity. This thesis draws on the concept of stimulus-response compatibility, which is well known in Human Factors, and applies this to the design ambient display. In addressing this concern, a series of studies are conducted to test combinations of LEDs (1, 2 or 3 LEDs) using different colours (red, blue and green), arranged in either compatible or incompatible combinations. We employ these LEDs to the linear and quadrant cooker-control layout. This was evaluated through questionnaires and experimental testing using a prototype. As expected, human performance is better when there is compatibility between the cues, while incompatible arrangements make performance worse and lead to confusion. We also found that there is no effect of ambient cueing when people use a quadrant layout (because the Stimulus-Response Compatibility is clearly defined by the mapping between burners and controls) and additional cueing is not required. However, there was a potential for the cueing to enhance performance in the linear arrangement, particularly when the cues are compatible. Furthermore, when the number of cues increases, performance time reduces, suggesting a benefit of redundancy in cueing. Finally, when incompatible cues were presented, performance became significantly and adversely affected; response times were slower and more errors occurred, compared to compatible arrangements. This suggests that the risk associated with malfunctioning ambient cueing could be higher than the benefits associated with performance improvements.

A small cross-cultural of cueing was also conducted. This used the questionnaire and experimental prototype and results showed little difference in preference or performance with the use of cueing. This is in contrast to preference work which had shown cross-cultural differences and suggests that the use of the cueing could produce a more uniform response

across cultures. From these studies, it is now suggested that provision of additional information could enhance consistency of response in the control-burner selection task.

Ambient cueing was further explored through Ambient Counter, a mock-up kitchen counter consisting of projected cues, cooking space, utensils and ingredients. The use of ambient cues in the Ambient Counter is to guide users through their cooking activities by using projection to highlight the correct ingredients to use in preparing traditional Malay dishes. A comparison of three forms of interaction was conducted; recipe book, ambient interface and smart chalk interface. Experimental evaluation shows that using a pointing device or a recipe book resulted in poorer performance than when the cueing was related to picking up specific ingredients. Thus, integrating the cueing with the actions leads to better performance. We also compared expert and non-expert cooks following the recipes and our analysis shows that both groups benefited from the ambient cueing.

Finally, the thesis considered the consequences on human performance when there are redundant cues, ambient display failure or interruption in the use of ambient cueing. This was intended to explore the potential impact of system malfunction on performance. Experiments show that distraction slows performance significantly and that participants get confused. This suggests that participants tend either to rely on their own expert knowledge and ignore any displayed information (as they are familiar with the recipes and ingredients) or tend to follow, believe and trust the information given by the system. The analysis also shows that if ambient displays fail, this leads to significant impairment of user performance. Furthermore, users tend to follow the information given by the system even though that information is wrong.

This thesis emphasizes the need to understand the users' perspectives and responses in any particular approach that has been proposed. Therefore, the main contributions of this thesis focus on approaches to improve human performance in the ubiquitous environment through ambient display. The proposed methods consider the nature of users' behaviours and the limitations of the technologies when they go wrong. Since the effect of the ambient display failure could be catastrophic, the research undertaken in this thesis is important to alleviate the problem that could affect both the user and the technologies.

In Memory of

Ku Azir Ku Ahmad
1958-2014
Al-Fatihah

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
Introduction

"In the beginning, the computer was so costly that it had to be kept gainfully occupied for every second; people were almost slaves to feed it." (Shackel, 1997)

After four decades of development, personal computers have become an essential medium of communication and information management in our lives. Modern lifestyles provide rich contexts for computers to support our everyday activity. We take for granted the fact that the computers we carry in our pockets (in the form of smartphones) can detect where we are and what we are doing, and offer services suited to these contexts. This shows that many computers are small and how they reach into our everyday lives. More than this, however, is the fact that small, embedded, digital devices have been fitted to many gadgets we use daily and which are designed to automate activity, to enrich human social interaction and enhance our interactions with our non-digital (physical) world (Poslad, 2009). In these ways, computers are no longer simply personal computers but have become ubiquitous and pervasive technologies which inform and shape our lives.

These embedded computers are often hidden in everyday items; digital camera, refrigerator, television, automobile or microwave. It is difficult to imagine, in any industrialised society, some aspect of everyday life which is completely computer-free today, or even harder to imagine a day which does is not affected by activities of computers. We are living in a computerised, automated and *digital world* which is so very different to living in the purely physical world of the past that we are only beginning to come to terms with this impact on our lives and behaviours.

Even though the use of these technologies has been a widespread focus of research in recent years, there remains a challenge to the discipline of Human-Computer Interaction (HCI) to evaluate human interaction with pervasive computing environments. A fundamental question for this thesis is whether this new form of technology requires a new form of HCI theory and practice, or whether revision of well-established ergonomics principles can be used for this challenge. The basis for this latter proposal is simply the assumption that, while the technology might change, the needs, requirements, behaviours and activities of those who will interact with the technology might remain constant over this time. Rather than having new forms of behaviour, people might be adapting their preferred forms of behaviour to the situations created by the new technologies. If this is the case, then it is worth running studies with the aim of appreciating how 'preferred' forms of behaving could either enhance or interfere with interacting with new forms of technology. So, the high-level aspiration of this thesis is simply to answer the question, What can Ergonomics tell us about how people might interact with Ubiquitous Computing (UbiComp)? This aspiration developed into the main motivation for the thesis which is outlined in the next section.

1.1 Motivation

It is proposed that, to date, research on UbiComp (Ficocelli and Nejat, 2012, Blasco et al., 2014, Bonanni and Lee, 2004, Bonanni et al., 2005, Bradbury et al., 2003, Brandon et al., 2006, Cheng and Bonanni, Fujinami et al., 2005, Green, 2009, Hanlon, 2005, Ju et al., 2001, Ko et al., 2007) has mainly focused on the development of technology and integration of hardware. The aim has often been to develop fascinating technologies which might be interesting, useful or fun – but there has been limited effort to conduct research into the human response to these technologies. UbiComp is a vast area with applications in a wide range of domains.

Thus, the first issue to address is the selection of a domain in which to consider UbiComp. For this thesis, the domain selected is the domestic kitchen and its UbiComp equivalent, the digital kitchen. While the focus of the thesis is on this very specific domain (and the challenges it raises) it is hoped that observations and conclusions can be applied more generally to the UbiComp challenge.

The domestic kitchen is a complex space in our home where multiple users carry out different tasks with numerous tools, work surfaces and appliances. The kitchen also contains many examples of technology, from cooking equipment such as the microwave oven to food preparation equipment, such as the blender, mixer, and food storage equipment such as freezer and fridge, as well as laundry equipment, such as the washing machine and tumble dryer, and other equipment such as a dishwasher. Not only do many of these devices contain embedded computers but they are also the focus of much interest in the UbiComp community. It is interesting to consider how the shift from embedded systems to UbiComp is developing: the main drivers for this shift seem to be two-fold. (i) The notion that the users of these devices can interact with the on-board computers, say to change settings or select pre-programmed routines, and the development of this interaction to create more opportunity for users to access information about the devices or the tasks that the devices can support, say in terms of video tutorials (presented on displays mounted on the devices or on kitchen walls) for performing particular tasks. (ii) Networking these various devices creates new opportunities for power management. This suggests that these devices present an interesting opportunity to consider how people will interact with devices which have traditionally been the ‘tools’ which allow people to perform everyday tasks and which are now sufficiently intelligent to offer advice and guidance to their users.

Not only is the domestic kitchen a cooking space but it also provides space for other activities such as washing, reading, or meeting other members of the household. The kitchen is a focal point of the house and, as such, a site where the use of different devices has to be combined with many other activities. This suggests that a focus on the kitchen is a good way of thinking about human interaction with UbiComp: it is a space which is already being considered as a prime space for UbiComp (so there are many examples of UbiComp applications to emulate); it is a space with well-established tasks and activities which can be supported by UbiComp (so the question of whether UbiComp helps or hinders these tasks can be explored), and it is a space in which many competing activities are performed (so the question of whether interruptions can be handled by UbiComp is relevant).

This thesis is concerned with how humans interact with UbiComp, with a focus on the digital kitchen. This question is particularly relevant as computers are shifting away from traditional desktops and turning into embedded computers. These technologies are meant to make devices more intelligent and helpful. A central issue concerns how helpful such intelligence really is and how, in the digital kitchen, devices can affect human activities.

While researchers (Hanlon, 2005, Ju et al., 2001, Lee et al., 2006, Olivier et al., 2009, Palay and Newman, 2009, Siio et al., 2004, Terrenghi et al., 2007, Wagner et al., 2011) have tackled this problem through hardware development, fewer studies have focussed on user trials in the digital kitchen. Without understanding how the activities work in the digital environment, the development of these technologies will become ineffective and unsuccessful.

1.2 Thesis Scope and Problem Statements

As stated in the earlier section, the domestic kitchen is a complex space in our home and with such multi-tasking in the work environment, interference occurs when multiple events compete for our attention at the same time. Things in the kitchen can easily go wrong if we lose track of the activity, e.g. burning pizza while drying clothes outside, or children scalded by hot water while their mother answers a phone call in the living room.

Therefore, within such a complex space, people might need help in the kitchen. Several forms of help can be provided for kitchen activities. For example, ‘scheduling support’ can help with time management when trying to cook two or more dishes at the same time, or a timer for a specific cooking task e.g. baking. Help can be given on the cooking activities for learners or individuals who have specific forms of illness or learning difficulties. An obvious form of help is to provide cooking guidance in a particular recipe such as by giving step-by-step instructions, ingredients required and tasks that need to be performed e.g. stir, fry, cut, chop etc. In the digital kitchen, such help information can be provided in the form of ambient displays (Palay and Newman, 2009, Bonanni et al., 2005, Alfonso Garate et al., 2005, Pham et al., 2012).

This thesis will focus on two main activities in the kitchen environment.

- Cooker control
- Cooking activity

Cooker control has been widely used in investigating human performance on understanding perception-action relations through Stimulus-Response Compatibility (SRC) in the mapping of cooker burners to their controls (Chapanis and Mankin, 1967, Chapanis and Yoblick, 2001, Chapanis and Lindenbaum, 1959, Chapanis and Lockhead, 1965, Hsu and Peng, 1993, Ray and Ray, 1979, Shinar and Acton, 1978, Wu, 1997). Norman (2002) suggested that cooker control layout provides a good example of ‘natural mappings’ to reduce the need to hold information in memory and to easily make an association between human actions and the environment in which they act. Norman also suggested that natural mappings should have no ambiguity, no need for learning or remembering, and no need for labels in the control set. The naturalness of the mapping should be such that the person, acting in their everyday environment, simply knows what action to perform and how to perform this. Thus, for example, people ‘know’ that the volume control on a music system needs to be turned clockwise to increase the volume. Of course, this knowledge is not something we are born with but something that we learn through our interaction with such devices. The naturalness, in effect, means agreement with the experiences that people have acquired during their lifetime of interacting with devices (Sanders and McCormick, 1988). When we encounter an object which does not match this agreement, we can become confused or make mistakes. It is proposed that this notion of natural mappings could be taken as a central premise for UbiComp, with a degree of mapping which is not ambiguous, does not require learning and remembering and does not require additional labelling. Wherton and Monk (2009) tested a range of different cues in the design of cooker controls for dementia patients by using a fluorescent wire around the cooker and control (see Figure 1.1).

Figure 1.1 Cooker Control mapping using Flurorescent Wire by Wherton and Monk, 2009

They found such cueing gave better performance than the non-light (conventional) design. However, their work only involved the mapping of a one-to-one relationship, i.e. be sure to operate the control which is lit with the same colour as a burner. This enhances spatial SRC. This raises the question of whether similar mappings could be achieved with more than one cue, and what might happen if there is a malfunction in the ‘mapping’ and the user is presented with cues which contradict each other. While it might be possible to vary to colours used, say green for one burner / control pairing, blue for another etc. it remains an open question as to what might happen if a technical malfunction occurs which changes this pairing. For this reason, the first investigation of this thesis will test the potential uses of ambient displays in cooker control in order to consider the impacts of more than one light and the possible effects of ambiguous or contradictory cueing.

Cooking is a practice or skill of preparing food by combining, mixing and heating ingredients. Food also can be prepared in a particular way such as authentic Italian cooking or traditional Malay cooking. Laudan (2013) proposed that cooking is a whole series of operations used by humans to turn raw materials into edible food. However, broader definitions have been offered by many food scholars such as Claude Levi-Strauss in his book *Le Cru et Le Cuit* which has been translated into English as "*The Raw and the Cooked"* (Maquet and Jacques, 1970) who also argued that cooking should be understood as heating that symbolised the difference between humans and animals. Wrangham (2009) argued that cooking food was an essential element in the physiological evolution of human beings. Meanwhile, Massimo Montanari (cited by Douglas, 2012), the Italian food historian, defined cooking as "*everything that has to do with food: modes of preparation, modalities of consumption, and rituals of conviviality*." Therefore, we can conclude that cooking involves ingredients, method, and utensils which define cooking as food preparation. On top of this, cooking requires actions to be performed in response to what can be defined as *instructions* (which can be either learned and remembered, or read from recipe books).

However, from the ergonomics aspect, cooking itself is an optimisation problem for either inexperienced or experienced cooks. It not only involves ingredients, method, utensils and instructions, but also a significant time spent both with our hands and our attention focused in order to meet the demands of the cooking tasks (Baumstark, 2012). Additionally, cooking requires the right equipment, space and technique to perform the task (Mitchell, 2010, Lowe, 2010) in order to minimize the risk of injury. For example, when frying eggs, the basic actions can be: (i) heat oil, (ii) fry eggs, (iii) flip eggs and (iv) serve. This list of simple instructions for *frying eggs* misses the fact that frying eggs actually requires more detailed and precise action before a perfect dish completed. For instance, the set of instructions could be elaborate for the specific goal of *cook eggs sunny-side up*:

i. Start with a hot non-stick skillet (pan) on medium heat
ii. Swirl a little butter in the pan
iii. Crack the eggs into individual bowls.
iv. Add the eggs side by side in the pan.
v. In about a minute, the outer edges will turn opaque. Then, cover the pan and lower the heat.
vi. Add a little seasoning.
vii. Wait for 4 minutes, the perfect sunny-side eggs will be ready.

Therefore, even a task as rudimentary of frying eggs is not a simple action of heating, adding, and flipping but can consist different styles of frying to produce different styles of eggs; for example, omelette, sunny-side up, scrambled, etc. The right equipment to fry eggs, e.g. skillet frying pan instead saucepan, and involves a set of action units (Hamada et al., 2005) such as 'break eggs' and 'add eggs', performed in a logical order; for example "fry eggs" should come after "break eggs", together with some time restriction, such as waiting for 4 minutes, and the correctly merging of action to complete the task. For example, if you like to cook over-easy eggs, start with sunny-side-up-eggs then flip the eggs when the outside whites set.

With respect to these actions, cooking becomes interesting to explore, especially in guiding cooking activities. In terms of UbiComp, such guiding of action can be seen in the many approaches to the development of the Digital Kitchen. Digital kitchens often present support for cooking and use the World Wide Web as a resource to find recipes (Hexus, 2012). These can be seen where people take their laptop displaying recipe on the screen into the kitchen (see Figure 1.2), although some people might be concerned about using their laptop in the kitchen (Woodruff et al., 2007). In many ways, the use of digital recipe books can simply be an extension of traditional approaches using paper. A recipe is a standard method with a similar structure, a list of ingredients followed by step-by-step instructions. On paper, a recipe can be presented in a cookbook, handwritten notes from friends or relatives, or printouts from a website. In some cases, recipes might not use clear instructions but provide some ambiguous information that needs experience to be understood.

Figure 1.2 Laptop on the Kitchen Counter, image courtesy of Hexus (2002)

Many of us use the kitchen as a laboratory to experiment with cooking new dishes. Therefore, people use different approaches to organising their ingredients. Some might prepare the ingredients first then cook afterwards, while others might prepare the ingredients as they become needed during cooking. Thus, a preliminary, short survey was performed in order to understand how people work in their kitchen environment.

The aim of this survey was not to develop a representative survey of kitchen habits or to contrast different cultures, but rather to get a sense of the flow of activity that took place in food preparation and the ways in which the space of the kitchen was used. This would help with decisions about the design of the food preparation experiment (discussed in later chapters).

Six participants (3 Malay and 3 British, aged between 25 and 40 years old) were recruited from among university colleagues. Their instructions were to take pictures during meal preparation, with an interval of 5 minutes between the pictures. Figure 1.3 shows a photo-strip of cooking actions when Malaysian participants prepare a meal and Figure 1.4 shows a photo strip of cooking actions when British participants prepare a meal.

Participant 1

Participant 2

Participant 3

Figure 1.3 Photo strips of meal preparation by Malaysian participants.

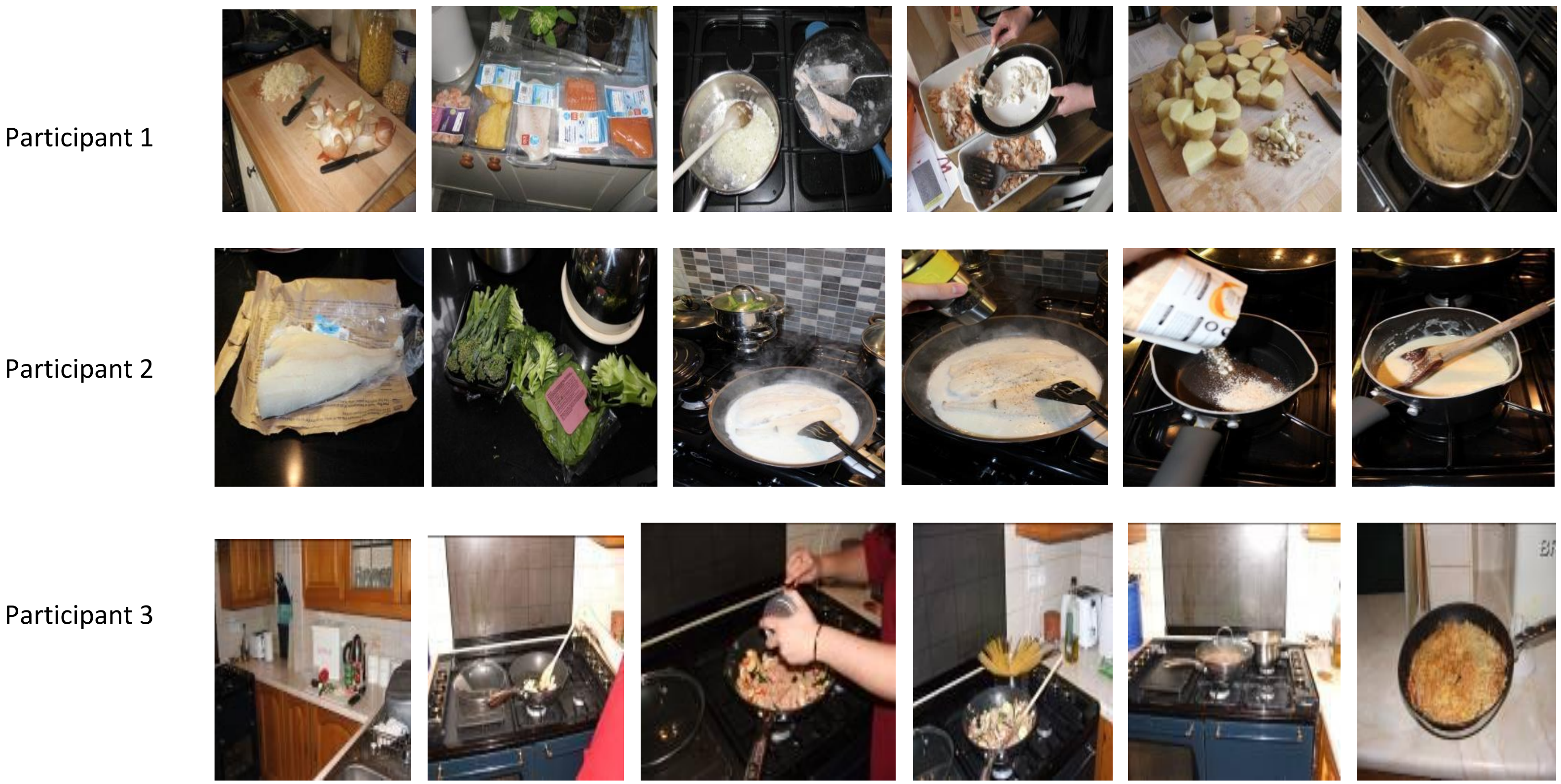

Figure 1.4 Photo strips of meal preparation by British participants.

Notice that none of the photo strips show reference to printed recipes. In these examples, all the participants were cooking meals using recipes that they knew and did not need to seek guidance. From the photo strips of meal preparation, almost all participants prepare ingredients first before they start cooking. Obviously, preparation involves ingredients that need to be washed, peeled, chopped or cut. Discussion with the six participants suggests that the reasons for this activity are (i) to reduce cooking times, (ii) to avoid forgetting the ingredients while cooking and (iii) to avoid burning the dishes while preparing the ingredients e.g. burning the oil while ingredients are still not ready.

However, there was some variation in this process. For example, Participant 1 (British) chopped potatoes towards the end of the cooking task. This was because he was worried that chopping the potato early might oxidize the potato (potatoes turn black if left too long in the open air) – although this could be avoided by placing the chopped potato in cold water.

The photo-strips show that some participants cook several parts of a dish at the same time. For example, Participant 2 (Malaysian) prepared fish, crab and squid (Strip 2 from left) to be cooked but started frying the crab first. While frying, she cooked rice at the same time (Strip 4 from left). Participant 3 (British) also prepared and cooked two dishes at the same time e.g. boil fish and fry onions; steam vegetables and sauté fish; boil spaghetti and fry ingredients. In both cases, the two ‘dishes’ were combined for the final serving. (For Participant 3 (British) the spaghetti was put into the same pan as the other ingredients.)

These photostrips show some parallels with television programmes by professional chefs. Despite knowing the ingredients and steps in cooking, when demonstrating a recipe, the professional chef will prepare ingredients before the show to reduce preparation time (see Figure 1.5). [1]Although TV cooks differ from the home cook, both groups show that they prepare ingredients first to save time before the real cooking begins. This suggests that a familiar pattern of arrangement (prepare / arrange ingredients first before cooking) can be used in this thesis experimental setup.

Figure 1.5 Ingredient arrangements in the professional cooking show, (L) Malaysian cooking show by Chef Norman Musa and (R) British cooking show by Jamie Oliver.

For the purpose of this thesis, it is assumed that cooking involves the preparation of the ingredients and their combination. These actions are largely performed separately. The preparation of ingredients is performed first, and the prepared ingredients arranged to hand in order for the cook to pick them up as required and then add them to the dish as it is prepared.

[1] Broadcasting time is too expensive to show all stages of a recipe in real-time, and for this reason time-consuming steps are taken in advance.

The combination of these prepared ingredients is therefore performed afterwards and there is little interweaving of these activities. While this is not meant to suggest that *all* cooking follows this format, it does suggest a strong trend that could be supported through ambient display in two ways: first, identity and support of the selection and preparation of ingredients; and second, to cue and monitor the sequence in which these ingredients are combined.

1.3 Research Approach

The approach taken in this investigation is an Ergonomics approach through experiments intended to measure human performance. Three main approaches are involved through this investigation.

- Questionnaire
- Hardware prototype testing
- User trials of cooking activities

Each element of this approach makes an important contribution to this thesis. The initial investigation used questionnaires to address two types of cooker control layout, linear and quadrant arrangement as shown in Figure 1.6.

By using a classic cooker control approach, pictures of four burner cooker layouts with a combination of 1, 2 or 3 ambient cues are given. Participants are required to indicate which of the ambient(s) cues map to the appropriate rotary knob. The second set of questionnaires is given specifically to identify population stereotypes of two different cultures - eastern and western - when responding to the ambient cooker. The paper-pencil test (questionnaire) is necessary in order to build an understanding of the problems associated with the cueing technique considered in this thesis. This approach measures and analyses the cooking control relationship of the ambient stove which later will be supported with hardware prototype testing.

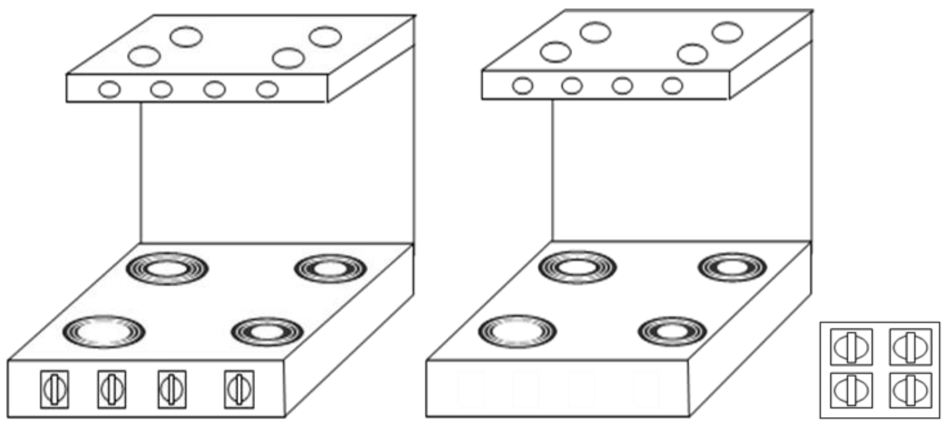

Figure 1.6 Linear and Quadrant Cooker-Control Arrangement

A hardware prototype is needed to better understand human performance. A model stove is built which operates the four cooker control layouts with three sets of ambient displays; red, blue and green. A combination of 1, 2 or 3 LEDs are tested either in the compatible or incompatible arrangement. Reaction times, number of attempts and response errors are measured within this test. The purpose of this test is to see how ambient displays can be implemented and to discuss their effect on human performance.

From simple cueing in the cooker control layout, the thesis is extended to complex cueing by embedding cues into cooking activities. An ‘ambient space’ is projected on top of the counter on which people perform cooking tasks. This is tested by user trials of cooking activities using real ingredients and equipment. The purpose of this test is to measure how different forms of interaction can guide cooking Malaysian dishes. Two different groups of participants will be involved; Malaysian and Non-Malaysian participants (to represent ‘expert’ and ‘non-expert’ cooks). Prior to the task, participants were asked if the ingredients and recipes were familiar to them. The degree of familiarity was used to indicate expertise. All the Malaysian participants were familiar with the ingredients and had cooked the recipes before; the Non-Malaysian participants had not cooked any of the recipes before and were also unfamiliar with many of the ingredients.

By providing real ingredients which have been prepared and arranged, the participants needed to assemble the dish by interacting with the ambient counter in different ways. Whenever a participant’s attention is directed to ingredients, a disc (green or red) will be projected on top of the ingredients. By using ELAN software (a professional tool for the creation of complex annotations on video and audio resources where an unlimited number of annotations to audio and/or video streams can be added) a video of the cooking task can be annotated in order to derive completion times, number of steps completed and percentage of errors.

Testing of the ambient counter is extended in the third set of user trials to see what happens if the system malfunctions. System malfunction involved an error in ingredient cueing (i.e. giving the wrong display to the right ingredient) or the intrusion of a step from another recipe into the primary cooking task. The test is to investigate human performance when an error occurs unnoticed. The cooking activities are completed by Malaysian participants through an ambient interaction. All the cooking activities will be recorded and actions will be annotated by using ELAN software.

1.4 Research Questions

In order to focus the research presented in this thesis, three research questions have been proposed.

1. How can ambient displays enhance human performance in the digital kitchen?

Ambient displays are intended to provide subtle cues to particular actions. These actions could relate to the use of equipment, e.g., operating controls on a cooker, or to food preparation and cooking. A series of studies will explore the impact of ambient displays on both types of action. The primary question is whether it is possible to identify advantages, in terms of performance, relating to the use of ambient displays.

2. How can multiple cues be designed in the digital kitchen environment?

From a simple display, the thesis extends the work to complex displays. Complex displays increase the amount of information (multiple cues) shown on top of an ambient counter. This work explores how multiple cues guide users in the cooking activities compared to the traditional method. Will multiple cues provide advantages of cooking activities by preparing real ingredients and cook the dish required by following the recipes either through recipe book or ambient recipes?

3. What are the consequences on human performance, of ambient display failure?

This was intended to explore the potential impact of technical failure on human performance on the use of ambient cueing. This is important to understand how users react to the digital environment when technology fails without their notice. An analysis of the number of attempts, number of steps completed and number of errors will help to determine when human performance will be worst both in the cooker stove layouts and in the user trials of cooking activities in the digital kitchen environment.

Overall, the thesis' focus is to understand the interactions among users and an ambient display. This will optimise the well-being and overall system performance in the design of future UbiComp systems, especially in the kitchen environment. The thesis will explore the kitchen activity in term of stimulus-response compatibility, user trials, the demands made of the user, the equipment used (i.e. cooker stove, smart chalk) and the information used (ambient display) to assess the fit between a user and the future UbiComp kitchen environment.

1.5 Overview of the Thesis

This section describes the layout of the document and is intended as a guide for selective reading. Problem statements and UbiComp framework is introduced in Chapter 2. Chapters 3 to 5 describe the design of stimulus-response compatibility in the four burner stoves through ambient cueing. Chapter 6 demonstrates user trials of cooking activity in the digital kitchen environment (ambient counter). Chapter 7 validates cooking activities when distractions occur. Chapter 8 describes the future works of this research and concludes everything that has been discussed in this thesis.

Chapter 2 – This chapter introduces the reader to a formal literature review and presents understanding of several important UbiComp terms. It starts by understanding the concept of 'ubiquitous' interaction from the Human-Computer Interation (HCI). The work will look at the differences between the traditional GUI and *implicit* interaction. Then the reviews will focus on the main concept of the thesis: *ubiquitous computing;* its earlier philosophy, works and its application in today's environment. Another important theme of ubiquitous computing are also reviews, *ambient display*. The reviews were carried out to build the concept of human-computer interaction using ambient display by divided the researchers' work into two categories; *simple ambient display* and *complex ambient display. In a*ddition to these reviews, the chapter continues with the reviews of manipulating ambient cueing through direct manipulation mapping, redundancy, multiple and failing cues. The reviews continue with works on *smart kitchen environment*, an area which become the most interesting area in the ubiquitous environment. In addition, this chapter reviews some of theory of skills, rule and knowledge-based behaviour and its implications for the ubiquitous environment.

Chapter 3 - This chapter, referred to as background work¸ explores how interaction in UbiComp can be considered in terms of stimulus-response compatibility (SRC). By using the questionnaire method, the efforts are to produce a preference linkage of cooker controls when ambient cueing displays were shown. The conclusion from this study show there is a strong relationship between task and display. Results contradict previous studies and show the preferred linkage (see Chapter 3) becomes the less likely linkage with one LED but becomes the best preference within the two or three LEDs.

Chapter 4 – This chapter is extended from the previous chapter and focuses on determining the population stereotypes in the four cooker controls between eastern and western cultures: Malaysian and British. The chapter starts with reviews and the impact of cross-cultures studies in the Human-Computer Interaction. While it is expected that preference linkages might be different between the two cultures, cueing information through ambient displays may close the gap in responses and interactions in the digital environment regardless of any demography. Results show that the preferred linkages (see Chapter 4) become the population stereotype of linkage preferences when involved with 1 or 2 combinations of ambient lights.

Chapter 5 - This chapter demonstrates SRC by a using physical model stove called Ambient Stove. Performed by two different groups of participants, Malaysian and British, preferences for linkages, response times and number of responses are measured and will be discussed in detail in this chapter. Response times are faster when the number of LEDs increases in the compatible arrangement.

Chapter 6 - To date, research on the 'augmented reality kitchen' has mainly focused on the development of technology and integration of hardware the domestic kitchen; less research has been conducted into the testing of these systems in cooking activity. This chapter explores the potential of user trials performing cooking activities in the Ambient Counter. The cooking activities involved Malaysian recipes which were performed with three different types of user interface; *Recipe Book* – presentation of traditional cookery instructions; *Ambient* – a Wizard of Oz simulation of the augmented kitchen in which projected displays change as the user picks up different items, and *smartChalk* - a projected display with a handheld pointing device. Results show that participants perform significantly better in terms of cooking times, number of cooking steps completed and fewer errors were made in the ambient interface condition.

Chapter 7 - Extended from a previous study, user trials of cooking activities with ambient interface condition were carried out with an additional effect: *cooking distraction.* The focus of the study in this chapter is to understand a user's perspective or behaviour when distracted and cues were not followed. Three distractions were given to participants randomly without their prior knowledge: *no system malfunction*, *simple system malfunction* and *complex system malfunction.* The analysis showed that errors often occurred in the system malfunctions condition when users intend to ignore the system guidance and continue cooking based on their expertise.

Chapter 8 – This chapter concludes all the theory, findings and summary of this thesis by answering the research questions and is followed by the foundation and directions for future work, which can build upon the ideas presented here.

CHAPTER 2
Literature Review

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser, 1991)

The history of modern computing started in the 1940s with equipment based on wired circuits, electromagnetic relays and vacuum tubes. Then, the development of the transistor and subsequent integrated circuits led to the era of mainframe computers. Computers were still expensive and complex at this time and only computer technicians had access to them. The next significant breakthrough in this history began in the early 1970s when Intel released the first commercial microprocessors and the first personal computer was commercialised by IBM in

1974. The rise of the graphical user interface, based on the Windows, Icons, Menu and Pointing device (WIMP) concept developed by Xerox in 1972 and commercialised by Apple in the 1980s, consolidated this second wave of computing. Computers have continued to become smaller and are now embedded in many of the devices we have in our homes. This defines the third wave of computing, in which computers become ubiquitous.

The order and diversity of the reviewed literature serves to illustrate how the "ubiquitous" concept has evolved within the context of human-computer interaction. Then, the chapter will explore the concept of 'ubiquitous' in more depth by understanding its definition, philosophy, aims and issues. Ambient displays are an important element in ubiquitous computing, and this thesis will review systems that use a multitude of everyday objects to display information, and their implementation in domestic settings. The exploration of ambient displays are then reviewed from the perspective of cueing effects; and how redundant, multiple and failing cues affect technologies and users. The impact of cueing upon users' knowledge will also be explored, as well as understanding users' behaviours from the perspective of cross-cultures and population stereotypes; which illustrates the different social contexts in ubiquitous technology adaptation.

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2.1 "Ubiquitous" in Human-Computer Interaction

The traditional graphical user interface (GUI) was designed to provide and serve interaction in an 'explicit' way - a design which supports the office environment with desktop computers, keyboard and mouse, and requires the user to explicitly request action that should be performed by the computer. The request for an action can be made using command-line, direct manipulation, gesture or speech recognition. 'Implicit' interaction, on the other hand, is based on the assumption that the computer has a certain understanding of our behaviour in the given situation or context (Schmidt, 2000). Selanikio (2008) added that implicit interaction occurs without the explicit behest or awareness of the user, and is often considered as an additional input to the computer while doing a task. Schimdt (2000) defined implicit interaction as "*an action, performed by the user that is not primarily aimed towards interact with a computerised system but which such a system understands as input"*. Unlike traditional desktop applications, implicit interactions force users to take a general view of a system where a lot of information is only exchanged implicitly, for example automatic light control (switches on the light when it is dark and someone is walking by) and active badge systems (automatically opens a door when someone with appropriate permission walks up to it) (Want, 1992) .

In traditional GUIs, the interactive system is the desktop computer with a fixed set of input/output devices. The emphasis is on combining software components to provide services to the user. However, in the implicit interaction, we are concerned not only with software services but also with devices and how to combine them. Implicit interaction with the user, within a given range of possible locations, reflects the freedom the user has to move about when interacting with the system. In contrast, desktop computing allows no such mobility; the user has to sit and stay in front of the machine (Salber, 1998).

Implicit interaction offers *invisibility*; which means technologies embodied in the environment, intuitiveness, anticipating of the user's intent, affordance and peripheral awareness. The interface disappears from the user's focus of attention so they can concentrate on the actual task at hand which offer greater manipulation directness (Salber, 1998). In the traditional GUI, to perform a task with a system, the user must consciously perceive, understand and manipulate an interface which is conceptually separate from the task being performed.

The implicit interactions fit with the vision of ubiquitous computing in which Gellersen et al. (1999) stated that the use of our physical environment and surroundings help display the digital information. This considers the technology as support and provides continuous interaction and natural interface — the walls of rooms, lamp, fans become interface for controls and communication to the world (Abowd and Mynatt, 2000) known as 'seamless integration'.

Seamless integration provides continuity with existing work practices and smooth transition between function spaces. The digital interaction (Ishii et al., 1994) between humans and computation will be less like the current desktop- keyboard-mouse-display paradigm and more like the way humans interact with the physical environment. Information in the digital environment is presented as "painted bits" (Wisneski et al., 1998) that need to be at the foreground of users' attention to be able to be processed. In order to provide a 'natural' interface, digital interactions need to support different actions of human behaviours and expression (Ishii et al., 1994). One way of considering this issue is to see the technology in terms of 'affording' a particular set of responses that the user can readily recognise and act upon (Gaver, 1991, Norman, 1999b).

An early example of implicit interaction can be seen in the prototypes of DigitalDesk. DigitalDesk (Newman and Wellner, 1992), demonstrated 'natural' interaction between artefacts and electronic objects by improving the functionality of a writing desk through the power of digital information (projected on to the surface of the desk). The benefits of a tangible interface are shown by embedding the advantages of digital manipulation into the drawing and writing task-specific environment. DigitalDesk Calculator (Wellner, 1991) records finger taps with a camera and microphone to provide a surface that serves as a touch screen calculator.

Another version of a 'digital desk' was ClearBoard (Ishii et al., 1994) which allows users to shift between personal space and workspace to support seamless integration by using everyday gestures such as head, movement, eye contact and gaze direction. By using transparent digitizer sheets and electronic pens, ClearBoard (see Figure 2.1) provides an interface of a sketch pad with colour pencil based on the drawing metaphor. It triggered the idea of changing a passive architectural partition such as walls, ceiling, windows, door and desktop to a digital interaction space where people can interact both in the physical and digital environment.

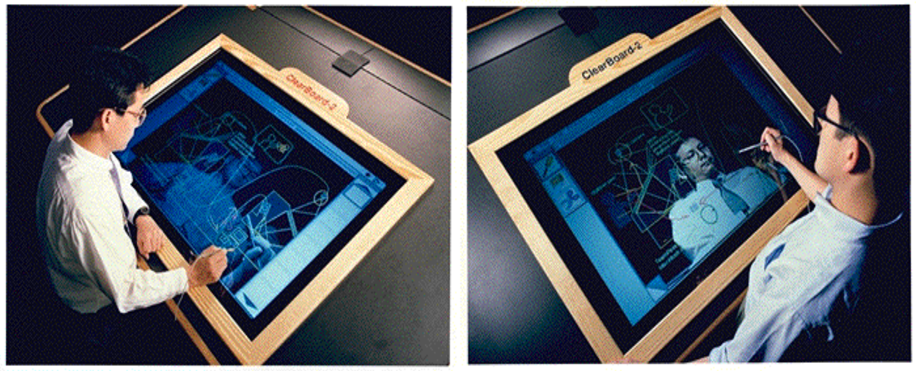


Figure 2.1 ClearBoard by Ishii.

Meanwhile, *The Proactive Desk* (Noma et al., 2004) allows users to handle both digital and physical objects on a desk without any mechanical links or wires, thereby preserving the advantages of the digital desk. Koike et al. (2001) developed an augmented desk system, *Enhanced Desk*, which integrated paper and digital information on a desk by providing information corresponding to the real objects (e.g. books) on the desk by using computer vision. Examples of applications built with the *Enhanced Desk* include Interactive Textbook (see Figure 2.2), Interactive Venn Diagram, Snap Link and two-handed drawing tool. Pearson et al. (2011) present *The Reading Desk System* which exploits direct manipulation such as drag-and-drop post-it-system for digital note taking to support active reading tasks.

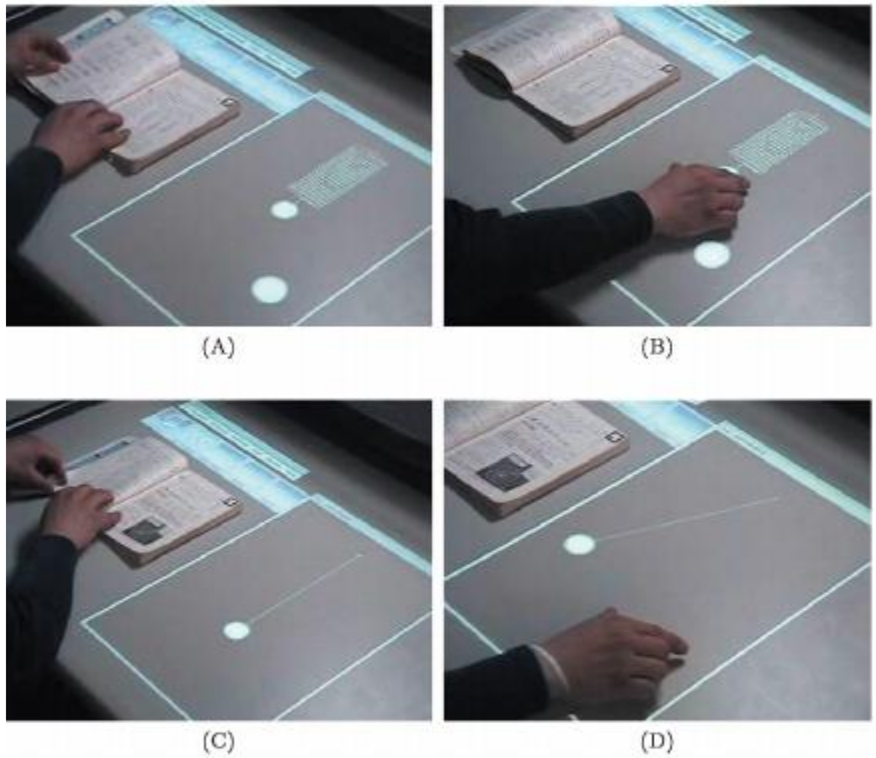


Figure 2.2 - Interactive Text books where (a) when a student reads a page describing a mass-spring experiment, CG simulation is automatically projected into a desk, (b) the student can manipulate the mass using his/her own finger, (c and d) as the student opens a page describing a pendulum experiment, another CG simulation is projected on the desk.

Schmidt (2000) concluded that implicit human-computer interaction is defined as an action, performed by the user that is not primarily aimed to interact with a computerised system but which such as system understands as input. He further identified that perception and interpretation of the users, the environment, and the circumstances are key concepts for implicit HCI. Now that we have an understanding of implicit interaction from an HCI perspective, the next section will explain the concept of ubiquitous computing and its application in today's world.

2.2 Ubiquitous Computing

The notion of 'ubiquitous computing' (or UbiComp, for short) was introduced by Weiser (1991) as the 'third wave' of computing technologies which defined it as mobility and transparency. UbiComp is characterised by small and powerful devices that are worn, carried, or embedded in the world around us – in doors, tables, the fabric of clothes and buildings, and the objects of everyday life (Dourish and Bell, 2011). As we explained the concept of *implicit interaction* in the last section, ubiquitous computing incorporates social aspects in interaction, such as culture, emotion and experience (Norman, 2002)

Norman (1999a) stated that the grand vision of ubiquitous computing is to appear everywhere, which enables information to be made available everywhere, and will support intuitive human usage by appearing invisible to the user. Norman (1991) coined the term *'invisible computing'* to reflect this trend of the 'computing' capability of products becoming hidden from the user's attention. Salber (1998) argues that, rather than force the user to search out and find the computer's interface, the interface itself can take on the responsibility of locating and serving the user in ubiquitous computing. This does not mean that the computer disappears or cannot be seen; rather it means that the user is able to maintain all or most of their attention on the goal they are trying to achieve rather than focus their attention on the computer. Chalmers and Galani (2004) point out that the '*invisibility'* of computing can become confusing and propose a focus on the *'seams'* at which physical and digital domains meet.

UbiComp has focused on technological infrastructures brought together by those concerned with the potential future of computational worlds and the possible relationship between people, practice and technology (Bell and Dourish, 2007, Weiser, 1991) which involve technologies that remain in the background until required but will work and adapt to our needs and preferences (Ley, 2007), and will be freely available everywhere (Greenfield, 2006). UbiComp has become an important part of users' lives but in ways that users do not really notice (Stylus, 2003, Poslad, 2009). For instance, Bell (2011), working as an anthropologist at Intel, showed that today's cars have become a proxy for ubiquitous computing. Ford developed a service called SYNC which allows drivers to make calls, play music and do other things using voice commands. Meanwhile Toyota Developed Entune, which allows drivers to connect their smart phones via Bluetooth wireless links. The plan is to make driving more personal by helping people's cars "talk" to them. Cisco suggests that there could be almost 15 billion devices linked to the internet by 2015, from televisions and gaming consoles to coffee machines and cookers. Bell (2011) concludes that ubiquitous computing is no longer the realm of science fiction - though the infrastructure of computing is still 'messy', Bell argues this should not be allowed to obscure the fact that it has become much more widely accessible.

Begole (2011) notes that the physical world already has a critical mass of devices and wireless networks, therefore the next step is to make those devices aware of how humans work and to get them to adapt to human habits. Therefore, current developments of advance wireless network infrastructures can be seen in richer countries in Asia such as South Korea; which plans for every home in the country having an internet connection with a speed of up to one gigabit per second. Meanwhile smart phones in Japan contain near-field communication (NFC) chips, (Negishi, 2014) which in effect turn them into mobile wallets that can be used to pay for groceries or trips on public transport. With the development of such technologies, embedded and networked-enabled devices have been collectively termed as the ‘internet of things’ (IoT) (Holler et al., 2014); which are able to facilitate richer context awareness, automated capture, integration and access of live experiences (Salber, 1998).

Weiser has inspired different sectors such as government and researchers across the globe that funded a large number of research projects to investigate how information technology could be diffused into everyday objects and setting. These include work from MIT’s Oxygen, HP’s CoolTown, IBM’s BlueEyes, Philips Vision of the Future, Orange-at-Home and Aware Home. An early project in ubiquitous computing was The ParcTab (Want et al., 1995). This project was designed as a preliminary test for Ubiquitous Computing in the Xerox Palo Alto Research Center (PARC). The system integrated a badge-sized mobile computer into an office network to enrich the computing environment by emphasising context sensitivity, casual interaction and spatial arrangements (Want et al., 1995, Want et al., 1996). As the person wearing a ParcTab walked into an office, sensors detected the badge and the corresponding user ID and then the network configured messages to that person to be sent to the telephone, and the person’s computer desktop to the computer, in that office. This work was used by Weiser (1991) to illustrate one of the basic forms of ubiquitous computing devices which he termed ‘tabs’, ‘pads’ and ‘boards’ (with pads being precursors of the tablet computers that are familiar nowadays and boards being large, interactive public displays).

Since the prototype of ParcTab, numbers of researchers have explored ubiquitous computing in our normal environment. For instance, *Classroom 2000* (Abowd, 1999) consists of a pen-based electronic whiteboard that enables an instructor to present and annotate a standard lecture, using a blank surface, a prepared presentation or a series of Web pages, as the background. Additionally, the classroom is equipped with digital recording infrastructure, and will automatically generate web-accessible notes that coordinate the captured lecture notes with the audio/video recording. Abowd et.al (1997) designed a number of prototypes of *Cyberguide* which used either indoor or outdoor positioning data to inform the system where the user is located. It uses this information to provide more salient information to the visitor about the surrounding space, such as building names for a campus tour or information about exhibits for visitors. Another version of applications of ubiquitous computing is *Domisilica* (Mankoff and Abowd, 1997), a project concerned with augmenting a home in order to provide automation of mundane tasks (e.g. turning down the stereo when the phone rings). The project also included a Web-based graphical interface to virtual environment that allows for remote interaction with the physical environment as well as with other virtual guests to the home.

In the UK, the Horizon Digital Economy Research team investigate how digital technology may enhance the way we live, work, play and travel in the future, respecting personal privacy whilst enriching the range of social interactions at work and at home. Their works includes Automics (Durrant et al., 2011), Brancomatic (Tennent et al., 2011) and others. Newcastle Culture Lab through Balance@Home Project (Seedhouse et al., 2014, Olivier et al., 2009) are a focal point for research in human interaction with ubiquitous computing, such as using an ambient kitchen as a platform for Task-Based-Learning (Seedhouse et al., 2014) through Learn Kitchen. Terrenghi (2007) create a cooking competence to support healthier food preparation. Meanwhile, fibre chopping board (Jackson et al., 2009) was designed and developed to track people's fresh food preparation activities in a domestic kitchen.

In the USA, University of Washington ubicomplab has produced a variety of works which focus on many areas of ubiquitous computing including novel user interface technology, energy sensing, health monitoring, embedded systems and human computer interaction. Their work includes SpiroSmart (Consolvo et al., 2004), a mobile phone based platform to analyse common lung functions to monitor pulmonary ailments such as asthma or chronic obstructive pulmonary disease (lung disease), and LightWave (Consolvo et al., 2004) a sensing approach that turns ordinary compact fluorescent light (CFL) bulbs into sensors of human proximity. They have also done work on sustainability sensing such as HydroSense (Philips, 2012, Mynatt et al., 2001) and ElectricSense (Mankoff et al., 2003, Ho-Ching et al., 2003).

Overall, ubiquitous computing involves networks of small, inexpensive, robust processing devices, distributed at all scales throughout everyday life. Weiser's visions of UbiComp open a new model and dimension for human-computer interaction, which diverts users attentions to the task from the interface, with the aims of making our lives more convenient, comfortable and informed. However, there is an enormous gap between the dream of comfortable, informed and effortless living and the accomplishments of UbiComp research. As pointed by Greenfield (2010) *"we simply do not do smart very well yet"* because it involves solving very hard artificial intelligence problems that in many ways are more challenging than creating an artificial human (Rogers and Muller, 2006). Rogers (2006) stated that the fundamental and difficult problems of designing UbiComp applications are to understand and cope with *what people do, their motivations for doing it, when they do it and how they do it.* Hence, while it is possible to develop simple UbiComp applications, it is proving to be much more difficult to build truly ubiquitous systems that can understand or accurately model people's behaviours, moods and intentions.

2.3 Ambient Display

Another dominant theme that has emerged in the field of Ubiquitous Computing is ambient display. Mankoff (2003) proposed an ambient display as *"the use of aesthetically pleasing display of information which sits on the periphery of a user's attention".* Mankoff further points out that the ambitious goal of ambient displays is to present information without distracting or burdening users. Though there are no solid definitions for ambient displays, a number of researchers explain their conceptions on the ambient display. For instance, Ishii et. al (1998) stated that the ambient display's information is moved off the screen into the physical environment, manifesting itself as subtle changes in form, movement, sound, colour, smell, temperature or light. It typically communicates just one, or perhaps a few at the most, pieces of information and the aesthetics and visual appeal of the display is often paramount (Stasko et.al). Meanwhile, Matthews et. al (2004) defined ambient display as peripheral display which aims to deliver or display information to users effectively and efficiently without demanding their full attention. While Stasko et.al (2004) refer peripheral display to systems that are out of a person's primary focus of attention and may communicate one or more pieces of information.

Pousman et.al (2006b) used the term *ambient information system* which refers to screen-based ambient displays. According to them, ambient information systems consist of (1) display information that is important but not critical, (2) can move from the periphery to the focus of attention and back again, (3) provide subtle changes in the environment and (4) are aesthetically pleasing. They also suggested that there are differences between ambient displays and ambient systems. Ambient displays are those that have pointed aesthetic goals and present a very small amount of information while systems are a subset of peripheral displays, which can appear either in the environment or on secondary or even primary computer displays.

By using the entire physical environment as a *digital display space*, ambient displays provide future interaction beyond the conventional graphical user interface (GUI). The objective of ambient is to broaden the interaction between human beings, sensitive and responsive to the presence of people. In general, ambient display is to explore new way of introducing information in the everyday environment (Holmquist and Skog, 2003).

Some researchers have explored the design of ambient displays through a wide range of physical medium such as wire, string, pinwheels, water ripples and bubbles. Other displays rely on projected digital images while some have converted the conventional everyday equipment into an augmented ambient product. The next two sections highlight and review some of these concepts which will be grouped into two categories; *simple* ambient work, which considers the works of using simple physical tools or equipment, and complex ambient displays; which considers the works that involve complex arrangements of displays.

2.3.1 Simple Ambient Display

Several attempts have been made to implement ambient display in small artefacts i.e. lamp, wall, chairs etc. “Dangling String” (Weiser and Brown, 1996), one of the earlier example of ambient displays, consists of an 8 foot piece of plastic which hangs from a small electric stepper-motor, mounted to the ceiling, which (driven by a microcontroller monitoring network traffic) would twitch as each packet of information passed by. As the networks get busier, the string would whirl noisily.

Holmquist and Skog (2003) developed a concept of *Informative Art* as a way to integrate information visualization in the everyday human environment, for example a composition similar to the style of the abstract painter Piet Mondrian showed the current weather in six different cities, or a piece of “landscape art” in the style of Richard Long gave a view of the last 30 days of global earthquake activity (see Figure 2.3).

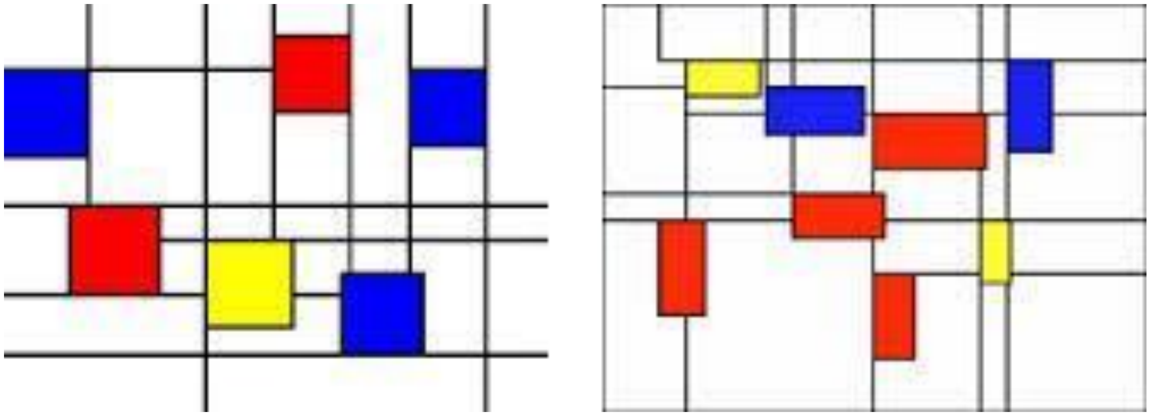


Figure 2.3 A Mondrianesque composition when initiated (L) and the same composition when changed according to the e-mail traffic (R).

Meanwhile, Rodenstein (1999) used a room's window as a location for a peripheral interface to explore the display of graphical weather forecasts, of activity in the space outside the window and of historical images of the space outside the window. Fujinami (2005) proposed AwareMirror by presenting relevant information (i.e. weather forecast or temperature of the day) in the mirror while brushing teeth. A number of digital information surfaces have been designed to meet the requirements of daily activities by changing the domestic artefacts into something valuable such as Active Wallpaper, WaterLamp and Pinwheels which display information such as weather or stock market (Wisneski et al., 1998).

Heiner (1999) presented *Information Percolator* in the form of air bubbles rising up tubes of water. By using sound cues, *Audio Auro* was prototyped to provide serendipitous information, via background auditory cues (Mynatt et al., 1998) tied to people's physical actions in the workspace. To measure the water temperature of tap water, *HeatSink* (Bonanni et al., 2005b) projected colour light into the stream of water by displaying *red* for hot water and *blue* for cold water (see Figure 2.4). These examples are considered ‘simple’ because they match a single parameter, e.g. water, temperature, network traffic, to a single medium e.g. coloured light, singing string.

Figure 2.4 HeatSink by Bonnani (Bonanni and Lee, 2004)

2.3.2 Complex Ambient Display

A number of studies have embedded ambient display into a complex form of structures and environments with other forms of ‘natural’ interaction i.e. touch, speech or eye gaze. To support digital information, *ambientRoom* was equipped with ambient media such as water ripples, active wallpaper with light patches and natural soundscapes to convey ambient information (Ishii and Ulmer, 1997). Similar to *ambientRoom,* the European project AROMA (Pederson and Sokoler, 1997) focused on a new display technology that had limited impact upon users’ attentions by employing abstract representations. Consistent with the achievement and development of ambient intelligence, Royal Philips Electronics announced its Ambient

Experience hospital solution in 2012, which aims to create a relaxing environment for patients undergoing imaging and radiation therapy procedures (Philips, 2012). Ambient Experience features the innovative use of dynamic light, video and sound to place patients in a calming, reassuring and relaxing environment by giving patients personalised control as shown in Figure 2.5.

Figure 2.5 Ambient Experiences by Royal Philips Electronics.

Consolvo (2004) evaluated the CareNet Display, an ambient display that helps the local members of an elder's care network provide her day-to-day care (see Figure 2.6). The prototype uses a touch-screen tablet PC housed in a custom-built beech wood frame which the interactive digital picture frame that augments photography of an elder with information about her daily life and provides mechanisms to help the local members of her care network coordinate care-related activities. Mynatt et al., (2001) proposed a work of *Digital Family Portrait* which uses an ambient display to provide distant family members of an elder with enough information to give them the peace of mind, whilst respecting the elder's privacy.

Figure 2.6 - The CareNet Display *in situ* where participants kept the display in places such as (from left to right) the kitchen, home office, TV room and dining area.

Other research has evaluated ambient displays in the office/academic environment. Mankoff et al (2003) designed and deployed two ambient display prototypes, the *BusMobile* and the *Daylight Display*, in the windowless undergraduate computing laboratories at the Univeristy of California, Berkeley. The BusMobile alerts lab users of how close several commonly used buses are to the nearest bus stop while The Daylight Displays provides information about the level of light that is currently outside. Ho-Ching *et* al (2003) designed an ambient display for the deaf that visualizes peripheral sound in the office where they conducted in-lab experiments and a one-week *in* situ evaluation for their Spectrograph display with one participant. Meanwhile, IBM's Everywhere Display (Pinhanez, 2001) is able to project digital information into nearly all the surface and objects in the physical environments. This approach is suitable to dynamically distribute simple messages in a room as in Figure 2.7. It can used to point to physical objects; show connections among them, attach information to objects and project dynamic patterns to indicate movement or change in the real world.

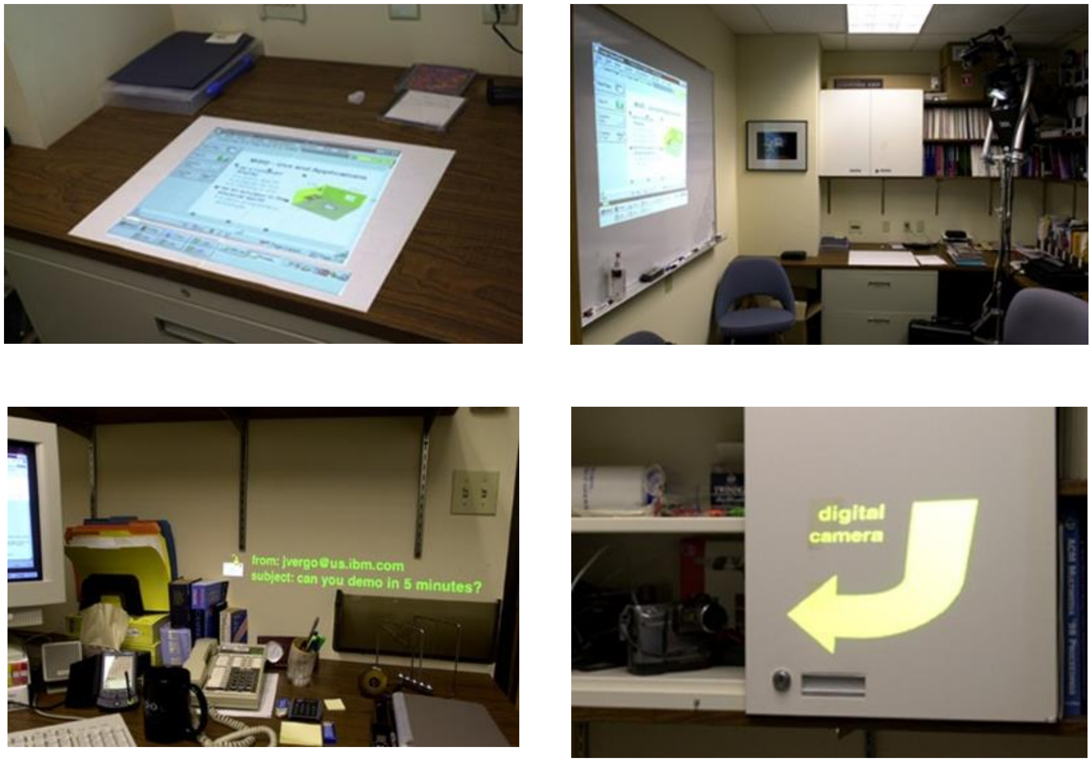


Figure 2.7 - IBM's Everywhere Display from clockwise: Interactive whiteboard, Locating equipment in an environment, Notification messages and display on desk.

Annotation of Kitchen (Bonanni and Lee, 2004) projected textual annotations in order to manage multiple events at one time from people working to playing to arrangements of cooking equipment. For example, to describe the contents of a refrigerator; text and pictures are displayed in front of the fridge door, the dishwasher displays information whether it's full or empty, clear or dirty and burners will light up to tell its temperature.

The difference between simple and complex ambient displays is one of quantity rather than type. The complex displays are just ones which have several simple displays in them, and often with each simple display being associated with a specific parameter. This becomes complicated because, rather than attending to a single source, the user is expected to filter a range of sources in order to detect something interesting. It is not obvious that selecting from several sources would be implicit – it is possible that the number of sources could become attentionally demanding and counter the notion of UbiComp.

Although ambient display seems to be an ideal way to saturate a user's environment with more information, it is unclear *how much information to display, what specific aspects to depict, and how exactly to display it, transparently or abstractly* (Pousman and Stasko, 2006a). Brewer (2005) stated that the designer should observe and interact with the users in their environment and see what information would be suitable for displaying. He also added that by watching the natural patterns of the user interacting with their environment it will hopefully become clear what kinds of information should be displayed first. While an approach based on observation is clearly useful to appreciate user's information needs, it does not tell us much about the impact of the display on performance, and for that a laboratory-based, empirical approach is needed. This thesis contains a series of laboratory studies directed at measuring the impact of ambient displays on various aspects of user performance.

Thus, it is important to address the problem of defining *appropriate methods for evaluating ambient display* and *measuring the impact of ambient information display*. Mankoff et. al (2003) defined a set of heuristics which have been used by a number of other researchers as an important evaluation tool for ambient display designers. For this reason, the next section will try to explore and understand how cueing can affect human performance referring to direct manipulation, redundancy, multiple, and failing cues.

2.3.3 Interaction Manipulation

We have looked into the implicit interaction which occurs without the explicit awareness of users by employing interactive or smart devices to do what they want whenever users are physically, socially or cognitively engaged. One way is to display a continuous representation of cues of interest in the environment using ambient displays. This form of display is defined as *direct manipulation*.

The term was introduced by Shneiderman (1983) which ideally involved continuous representations of objects of interest and rapid, reversible, and incremental actions and feedback (Kwon, 2011). In the beginning the concept was proposed in the context of office applications and the desktop metaphor, which were the basis of the dominant graphical user interface WIMP (Windows, Icons, Menu, Pointer). The idea of direct manipulation started on display editors and complex linguistic commands which allowed users to manually insert space or text and move blocks of material physically on the screen (Frohlich, 1993). Therefore, from this work Shneiderman refers systems that have the following virtues: (Shneiderman, 1983, Frohlich, 1993, Hutchins, 1985) :

- Novices can learn basic functionality quickly, usually through a demonstration by a more experienced user.

- Experts can work extremely rapidly to carry out a wide range of tasks, even defining new functions and features
- Knowledgeable intermittent users can retain operational concepts.
- Error messages are rarely needed
- Users can see immediately if their actions are furthering their goals, and if not they can simply change the direction of their activity.

Since then, a number of works on direct manipulation can been seen, many in computer-aided design and manufacturing. For instance Bill Budge's Pinball Construction Set (Budge, 2013) creates an infinite variety of electronic pinball games by directly manipulating graphical objects that represent the components of the game surface, followed by other examples such as the area of intelligent training system (Williams, 1981; Hollan, 1987). Spreadsheets are another example that incorporate many of the essential features of direct manipulation.

However, subsequent developments and changes in direct manipulation represent a different model of interaction. Hutchin and colleagues (Hutchins, 1985; Frohlick, 1993) for example propose 'directness', which is related to both the psychological *distance* between user goals and user actions in the interface, and to the psychological *engagement* of feeling oneself to be controlling the computer directly rather than through some hidden intermediary. They refer *distance* to the mis-match between the way a user normally thinks about a problem domain and the way it is represented by a computer, while *engagement* refers to a particular style of representation based on a model world metaphor rather than on a conversational metaphor of interaction (Frohlick, 1993; Hutchins, 1985). They conclude that direct manipulation is a system that minimises distance and maximises engagement and are said to present the most 'direct' kind of interfaces to users.

Alternatively, Hutchins (1987) promotes mixed mode interaction in a discussion of *Metaphors for Interface Design* by promoting three types of metaphors commonly used in interface design; activity metaphors, mode of interaction metaphors and task domain metaphors. Concentrating on mode of interaction metaphors, Hutchins describes four elements which are conversation, declaration, model-world and collaborative manipulation. Here, Hutchins defines direct manipulation as supporting the model-world metaphor where "expression have the character of actions taken in the world of interest" and argues that some referential distance is required to support abstract reference to unseen objects. This leads Hutchins to propose a collaborative manipulation metaphor for human computer interaction which is characterised by combining the conversation with an intelligent agent with manipulation of objects in a model world.

Laurel (1997) promoted 'first-person' interfaces in which the user feels him or herself to be acting directly on some model world (rather than indirectly through some hidden intermediary). Laurel suggests that the interface agent is a convenient new metaphor for representing the more pro-active and autonomous components of modern computer systems which may include various facilities such as information filter, remind, help, tutor, advise, perform or play.

As the emergence of ubiquitous computing promises to bring digital information to the walls of an everyday environment, Terrenghi (2005) suggested a gesture-based direct manipulation paradigm for environments by mapping the elements of GUIs to objects in the real world in order to provide affordances for new interactions. This has been described in the context of affordance as properties of the world defined with respect to people's interaction with it.

Terrenghi suggested that two main aspects can be address when designing affordances of digital information: (1) the visual appearance of the displayed information can suggest the gesture to be performed just by relying on shaped and visual cues and (2) metaphoric link to real world objects and to their affordances in the physical world can provide rich material for the design of affordances for digital information. Terrenghi also stated that the design of affordances for digital information in the real physical environment implies the consideration of new aspects which differ from the desktop PC environment. The user's ability to move around in the space and to directly manipulate objects and information items needs to be supported by interfaces that are properly scaled to the user's metrics, location in space and motor capability. Therefore, the design discipline will need to merge screen and product design competence, in order to merge virtual and physical worlds.

While ubiquitous computing provided direct manipulation by mapping the elements from both virtual and physical worlds, we also need to consider the multiple, redundant and failing cues in the digital environment associated with multiple probabilistic cues. The questions are concerned with what to expect and where to look in the complex display. Therefore, attentional mechanisms must be prioritised and select information relevant to the behaviour. This can be simply done by applying cues in the settings. A cue can be visual, auditory, tactile or multimodal in nature. Cues can also range from being quiet and subtle to being loud and intrusive. The inclusion of different cue information is important since it is not just visual cues in particular that may have weaknesses when it comes to object recognition, but any cue in isolation (Aboutalib, 2007). Aboutalib also argues that some cues may be more indicative of an object than others and thus the evidence given by that cue should have greater influence. Therefore, to reflect this fact; weight (the strength of the association between an object and cue) are added; whose value represents the strength of the association between a particular cue and object for each possible cue and object. Meanwhile, Chan (2000) proposed a new paradigm of contextual cueing which aims to understand how contextual information is learned and how it guides the deployment of visual attention/behaviour.

Redundancy occurs when different cues such as dynamic sights, sounds and other stimuli that convey the same information compete for the user's attention (Hoch, 1985). Redundancy in natural ecology implies that cues can indicate the presence of other cues and can thus lead to cue co-occurrences. Weindenbacher (1997) stated that redundant coding is a format variation which permits the identity of each symbol type to be accessed independently through two separate cues. These cues may be drawn from different perceptual dimensions (e.g. color and orientation). There are two types of redundancy; distributional redundancy refers to marginal distributions and correlation redundancy is a measure of the extent to which two variables are correlated which become the interest of this study. Studies have revealed that cue redundancy is confounded to a greater or a lesser extent with the cue validity and/or task predictability, as well as with cue-regression weights. Weidenbacher and Barnes (1997) examined cognitive dimensions of search performance involving a redundantly coded system and found that visual search was more efficient for redundantly coded systems than for symbol encoded systems. Taraswich et. al (2003) investigated notification cues, which indicate the status or availability of information that is of interest to a particular user in a ubiquitous setting. Studies of redundancy have focused on the effects of redundancy on performance, and results have shown that dependencies among cues indicate that cues represent the same distal event (Armelius, 1976). Therefore, given the options to choose stimuli-response, subjects prefer redundant structures which they believe represent a certain event that contributes no new information about the criterion. Oskamp's (1965) studies have shown that with a higher number of cues, subjects have more independent information about the criteria. As the number of cues increases subjects feel more confident even though they are unable to utilise the information to increase their accuracy. Studies have also shown that subjects are more confident in a redundant structure than in non-redundant structures where dependent cues represent the same event. This gives them greater confidence when they predict a certain event from a set of dependent cues than if they make the same prediction from a set of independent cues. Subjects also have a tendency to believe that cues are correlated and relevant even if they are not by considering both cues when they made their judgements in a two-cue task, although they knew nothing about the relevance of the cues.

Meanwhile, Schank define failing cues as “expectation failure” when the sensory information is inconsistent with the expectation, and it is the expectation that is deemed to have failed. Rumelhart and Ortony (1976) suggest that finding a good fit between expectations and input is a critical part of the strategy for selecting appropriate memory structures from an enormous number of possible schemata - a context-directed selection process. From this perspective, expectation failure is not the cue for learning, but for eliminating the schemata responsible for the failed expectations from the set of potentially appropriate schemata for comprehension of the current situation.

With respect to these findings, Proctor and Vu (2012) define these as *cueing effects* which contain the following characteristics.

- Stronger cueing effects are archived when the cue and target stimuli occur at the same spatial location, although non-allocated haptic cues can be just as effective when there is a logical mapping between the cue and target location.
- Better performance for stimuli occurring at the cued location than at uncued locations is attributed to attention.
- Kinesthetic stimuli seem to superior to visual stimuli in alerting attention, are generally faster than visual or auditory response.
- Performance is enhanced if information coming from more than one sensory modality is presented from approximately the same external location.

- Auditory and tactile cues are more effective at directing visual attention than vice-versa; may be more automatically alerting than visual stimuli.

2.4 Smart Kitchen Environment

As numbers of UbiComp technologies have been widely explored in different research topics and areas, computers are starting to migrate into the domestic space expanding the horizons of UbiComp's interest in daily life including a wider range of user population, activities and space. An example of an environment enhanced with ubiquitous computing technologies is a smart kitchen environment. The smart kitchen environment is a popular focus of attention for developments in the field of Ubiquitous Computing (UbiComp) and Ambient Intelligence (AmI).

The idea of a smart kitchen has been pioneered by MIT in their CounterIntelligence Projects (Bonanni et al., 2005b, Bonanni and Lee, 2004) and there have been numerous follow-ups in the last decade such as Smart Kitchen Minoh Laboratory (Tsuji et al., 2012, Hashimoto et al., 2012, Yamakata et al., 2011, Ueda et al., 2011), Nutrition-Aware Cooking in Smart Kitchen (Chi et al., 2008), IBM Smart Kitchen (Blasco et al., 2014) and smart kitchen from Newcastle Culture Lab (Olivier et al., 2009). This is the concept of a kitchen environment which is designed to make activities in the kitchen more convenient through the use of ubiquitous and ambient technologies which are embedded into the kitchen space and equipment. The smart kitchen's concept is to support the cook's activities at the precise time he/she needs it by recognising the cook's behaviour, his/her cooking skills, and the kitchen environment dynamically and decides whether he/she needs support or not and which kind of support is suitable for the situation as shown in Figure 2.8.

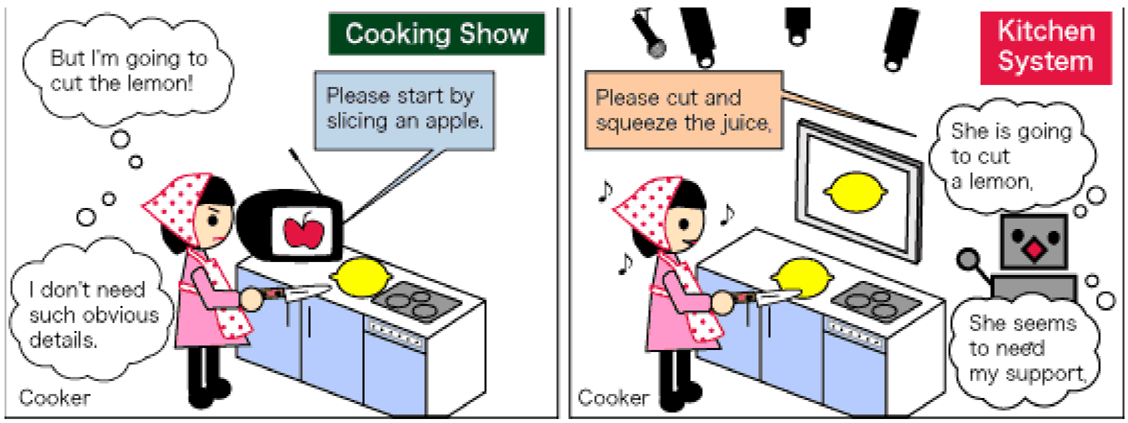


Figure 2.8 Illustration of Smart Kitchen Environment assisting cooker. left (L) picture is the system initiated while right (R) picture shows a user initiated or smart kitchen cited from Minoh Laboratory, Kyoto University.

The *Ambient kitchen* (Olivier et al., 2009) is a high fidelity prototype at Newcastle University Culture Lab with simultaneous capture of the multiple synchronized streams of sensor data by allowing evaluation of pervasive computing prototypes. Bonanni presents *Counter Intelligence* (Bonanni et al., 2005a, Lee et al., 2006) by embedding projecting information into its objects and surfaces. By doing so, it is expected that it can coordinate between multiple tasks and increase confidence in the system (Figure 2.9). Meanwhile, Chi et al. (2008) present a smart kitchen by giving calorie awareness of ingredients when preparing meals. It consist of a smart kitchen, stove, counter and cabinet to provide real-time feedback through awareness display.

Figure 2.9 Augmented Kitchen Reality by Bonanni

Blasco (2014) presents an implementation and assessment of a *Smart Kitchen* which provides Ambient Assisted Living services to increase elderly and disabled people's abilities in their kitchen-related activities through context and user awareness, appropriate user interaction and artificial intelligence. Meanwhile, Luo (2009) developed a smart fridge with the focus on health and nutritional habits as well. Similarly, Mankoff et al. (2002) suggest a system which captures and accesses an application that could generate a healthier shopping list by using the information from former shopping receipt data. Other research also suggests generating a shopping list by retrieving information about the food stock from the fridge (Li et al., 2009, Gu and Wang, 2009). The Diet-Aware Dining Table (Chang et al., 2006) tracks what and how a user eats and presents a smart kitchen which provides nutritional information to family cooks to help make informed decisions about healthy eating. Wagner (2011) envisioned a context-aware recipe retrieval system that guides and supports people to increase their cooking competence. A Context-Aware Personal Diet Suggestion System proposed by Huang (2010) helps users have a healthier eating habit. Unlike the earlier presented food recommendation systems, this one is based not only on food stock and user information but also on the activity of daily living.

Several attempts have been made to develop digital recipe books for use in the 'ambient kitchen' (as discussed earlier, an ambient kitchen combines digital technology, in the form of screens around walls, projections onto work surfaces, or illumination of objects in the kitchen). *Living cookbook* (see Figure 2.10) enables people to share their cooking experiences, educate others and because the recipes might be provided by family or friends, provide a sense of presence and sociability (Terrenghi et al., 2007). A preliminary usability test was performed with four participants (2 men and 2 women) to test the system by using a 'talk aloud' protocol by asking two of the participants to record the recipe and the other two to playback the recorded video and cook along. Findings from this preliminary test show that the playback video is more interesting and the cooking session is more interesting for the learning user.

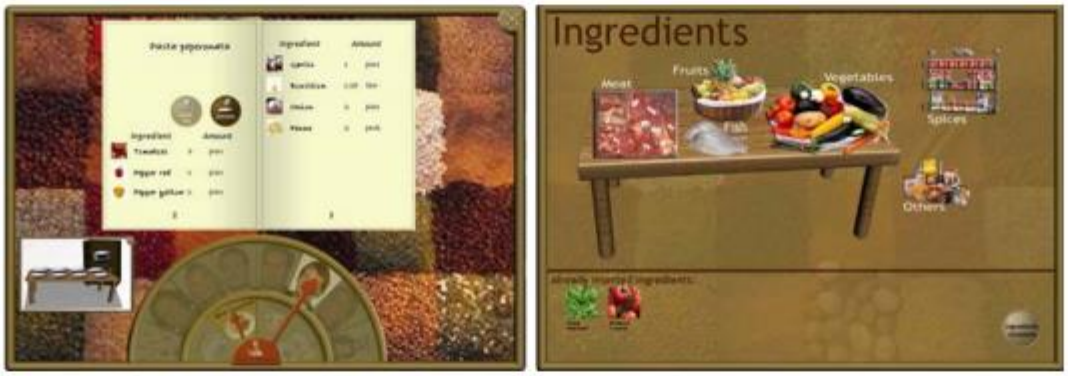


Figure 2.10 Two sample screen of the user interface of Living Cookbook (Terrenghi et al., 2007)

A similar concept SuChef, supports last-minute meal decisions by displaying a list of everyday recipes from one's friends and family. The prototype of SuChef was created – a kitchen display that displays a list of everyday meal ideas or suggestions to help users find cooking inspiration (Palay and Newman, 2009). Results from the prototype show that the structure shifts eating habits and provides a variety of everyday meals.

The Kitchen of Future (Itiro et al., 2004) supports automatic generation of web-ready recipe pages when users perform cooking activities: images of the cooking workplace are captured and the cook is able to provide voice memos into multimedia recipes. The work implements various electronic devices into a standard kitchen unit. This work suggested that it is important to represent information without having the user changing his/her view. The distance between the user and system should be minimal. One can see how these could be combined with Living Cookbook (discussed above) to support the creation of content.

Cooking Navi is an assistant for daily cooking in kitchen developed by Hamada et al (2004). It helps users cook recipes by following the text, video and audio provided by the system by splitting up each recipe into basic Action Units (AUs) that have a logical order. For example, AU "break eggs" needs to be done before "fry eggs". It provides multimedia cooking navigation through several recipe books similar to *The Kitchen of Future.* A preliminary experiment was performed with 8 participants (2 experienced, 3 intermediate and 3 novice cooks) with the system, who were required to cook 2 difficult recipes selected from 4 recipes and participants evaluated the system using a questionnaire. Two of the novice cooks were able to complete 2 dishes that they may not have been able to complete had they been given the ordinary text recipe. The participants evaluated the system as more helpful than a video or text recipe.

Counter Active (Ju et al., 2001) is an interactive cookbook for the kitchen counter. The initial idea was to transform the work surface into a large touch screen for interacting with instructional, step-by-step, projected information. Like a cookbook, Counter Active (see Figure 2.11) provides instructions and pictures showing how to cook various recipes, but it has the capability to provide movies, music and help on demand. By pressing on worlds or highlighted 'hotspots', the user can get instructions and support multimedia content, step by step instruction in the same space. A preliminary test was conducted with two children aged 10 and 7 to complete the kids' recipe. Results showed that visual cues were effective in choreographing movement and that the children relied heavily on the videos to demonstrate actions. This suggests that, particularly for people with little or no cooking experience, following a video can be beneficial in performing cooking tasks. However, it is not obvious that it was the projection onto a work surface, rather than the use of video which was helpful; the same presentation could have been made using a touch screen, such as an Ipad. It was disappointing that the system did not respond more fully to the actions that the users made on the work surface, e.g. in terms of cueing actions by indicating ingredients or objects to use.

Figure 2.11 Illustration of screenshot from CounterActive (Ju et al., 2001)

eyeCook (see Figure 2.12) presents a multimodal cookbook to help a non-expert computer users cook a meal (Bradbury et al., 2003). Users interact with the eyeCook through eye movement and speech commands and are required to wear a headset for speeh control and an eye tracker interprets the user's gaze. It responds visually and verbally by providing 'read aloud' instructions and ingredients. Additional information such as nutritional information, definitions of ingredients, cooking utensils and history of the dish are also given during the cooking activity. The system also makes a suggestion on what other dishes can be served with it. The system has never been tested with any experiments or user trials.

Figure 2.12 eyeCOOK display mode (Bradbury et al., 2003)

Lei (2012) designed a system that focuses on activity recognition in the kitchen by using an RGB-D camera which identifies activity and tools used by identifying shape and colour. Ficocelli and Nejat (2012) present an assistive kitchen that incorporates speech communication and an automated cabinet system to facilitate the storing and retrieving of items and to obtain recipes for meal preparation. Meanwhile, Schwartze *et. al* (2009) present their work in graphical interfaces for smart environments with the “4-Star Cooking Assistant” application which proves the capability of their system to dynamically adapt a graphical user interface to the current context of use. Several prototyped kitchen objects have been made to be integrated with an AmI (ambient intelligence) such as Intelligent Spoon (Cheng and Bonnani, 2006) which is able to measure the temperature, acidity, salinity and thickness of food or Chameleon Mug which determines the temperature and sugar level of liquid and even the state of the milk.

From the reviews, we can say that the paradigm of ubiquitous technologies has become widely explored through different types of environment which actually raises many challenging issues not only for computer science and engineering but also in ergonomics. Norman (1998) stated ubiquitous computing appliances required three axioms of design: simplicity, versatility and pleasurability to aid existing task situation. This, however, actually brings additional and new ergonomics problems to solved. The main ergonomics concern in ubiquitous computing is to establish conditions for cross-disciplinarity oriented toward the behaviour of complex socio-technical systems (Shackel, 2000). Abowd (1999) stated that research of ubiquitous systems should be subjected to real and everyday use and should be evaluated to determine its impact on the user community. However, there is very little work that provides detailed study of the impact of technology on human performance.

Lyytinen and Yoo (2002) argued that implementing ubiquitous computing requires implementing and managing two layers of computing capability: infrastructure and services which present new social and technical challenges. They also stated that ubiquitous computing would be substantially better if we had representations that more properly and more formally considered the role of information technology in work and in our lives. Therefore, from the ergonomics perspective, one design challenge of ubiquitous computing application will be determining what kind of balance of intelligence to maintain between the edges and the center of the network. Shackel (2000) suggested that ergonomists should work more closely with software designers to build applications or systems that include human factors strategies and are truly comprehensive. Another issue is concerned with trust and behavioral intentions and usage behaviours such as (1) at what degree an individual believes that using the system will help them perform their job better, (2) the degree of ease associated with the use of the system and (3) the degree to which an individual perceives that others believe that they should use new system (Al-Gahtani, 2007). Now that we have reviewed some of the applications of ubiquitous computing applications and its issues and challenges, we will review the work on user behaviour from the perspective of cross-cultures and population stereotypes studies.

2.5 Cultural Impact on Ubiquitous Computing

Culture is the collective programming of the mind which distinguishes a group of people from others where people from different cultures are different in their perceptions, cognition, thinking styles and values (Geert, 1991 cited by Wu, 2009). Choi (2005) added that cultures cover a wide range of intangible aspects that includes thoughts, values, attitudes and behaviour. Marcus (2002) argues that in a global business, difference may reflect worldwide cultures and "the impact of culture on the understanding and use of technologies should be taken into account". Proctor (2012) believed that the stereotypical response is the one that occurred most frequently, and the percentage of individuals giving that response is an indication of the strength of stereotypes. However, other stereotypes are a subset of experience and learning within a particular culture and therefore are culturally specific. As an example, Bergum and Bergeum (1981) presented a study of response towards everyday items such as a light switch, door with the knob on the left and lever handle faucet with 127 American students. From this study, 88% of the participants indicated that the up switch represents on, 72% that a door with the knob on the left should open inward and 93% that upward movement of the faucet level should turn on the water.

Thus, it is interesting to consider whether there might be cultural effects when interacting with UbiComp. For example, is it possible that people from one culture might interpret the cues from UbiComp in different ways to those from another culture? Previous work exploring population stereotypes between different cultures (typically 'Western' cultures such as US compared with 'Eastern' cultures such as China), have shown some differences, but these are not always consistent across studies as we shall see in chapter 4.

There have been many studies on cross-cultural issues that mostly focus on the user interface design of world wide web (Kersten, 1999; Badre, 2001; Osuna, 1998; Marcus, 2000; Luna, 2002), desktop PCs and mobile phone. Badre (Badre, 2001) investigated several key issues and questions related to the cultural context of Web interface design. The results showed that cultural practices and preferences in Web sites were influenced both by country of origin and genre. For instance, Middle Eastern sites in Arabic and Hebrew have a high frequency of orienting text, links and graphics from right-to-left, as opposed to centering or left-to-right. Results have also shown that Brazilian websites indicate a cultural preference for many colors.

The findings from anthropologist Edward Hall and Geert Hofstede (Lonner, 1980) on cultures provide the basis for the analysis of Web sites. Their findings include a set of categories into which we can systemise culture, for example preferred message spread. Marcus (2000) conducted a study by analysing some of the needs, wants, preferences and expectations of different cultures through references to a cross-cultural theory developed by Geert Hofstede. Meanwhile Luna et. al (2002) examine some of the site content characteristics that can lead Web site visitors to an optimal navigation experience, in a cross-cultural context particular in a cognitive framework. On the other hand, Kim and Lee (2005) tested icon recognition between American and Korean, the results of which show that Korean participants performed significantly better with sets of concrete icons compare American which showed opposite tendencies.

The most well-known cross-cultural study on mobile phone was by Nokia in India, which reported that Eastern cultures display different consumer preferences which gave them an overview of users' activities within cultures. The findings show that Britsh users found that *"Samsung mobile phones are very complex"* while Korean users said *"Nokia mobile phones are too simple".* Cha et.al (2005) investigate the user interface (UI) preferences in the UK and Korea for mobile phones with two types of studies; quantitative (questionnaire) and qualitative (user evaluations). The quantitative analysis showed that there are strong differences in the preferences for mobile phone brand between Korean and British users where the mobile features and style of communication Korean users frequently utilise are different from British users. While from the qualitative results, British users tended to analyse wording and instruction from an analytical viewpoint, did not like features that were too complex and preferred simpler views, whereas Korean users preferred looking at the whole of the first level of menus all at once from a holistic viewpoint and were frustrated with features that looked too simple. Campbell (2007) studied cross-cultural comparisons of perceptions of mobile phone use in selected public settings with a sample of participants from U.S. Mainland, Hawaii, Japan, Taiwan and Sweden. Results showed that Taiwanese participants tended to report more tolerance for mobile phone use in a theatre, restaurant and classroom than from other participants. Japanese participants were more tolerant of mobile phone use in a classroom, but less tolerant of use on a sidewalk and on a bus.

Harris et. al (2005) found significant differences between the UK and Hong Kong in usage of and attitudes to m-commerce services. Hong Kong respondents are consistently less satisfied with m-commerce services there than in the UK. Meanwhile, Dai et.al (2009) found that US and Chinese m-commerce cosumers were similar in their perceptions of privacy, innovativeness, value-added, usefulness, ease of use and compatibility. But the value of perceived enjoyment is higher among US consumers, while Chinese consumers have high concern for m-commerce costs.

Cross-cultural studies of ubiquitous computing applications, however, are relatively rare, perhaps because the concept is still new. It is taken for granted that different users in different countries have different usability criteria. An understanding of the cultural dimensions can aid developers and designers immensely in developing appropriate ubiquitous computing applications in order to understanding the user's context, which requires conducting cross-cultural studies in unique and challenging locations.

A simple, three-stage human behaviour classification was developed by Rasmussen (1983). Essentially there are three types of human behaviours; skill, rule and knowledge-based behaviour. This framework refers to the degree of conscious control exercised by the individual over his or her activities.

The skill-based behaviour represents sensory-motor performance during acts or activities which, following a statement of an intention takes place without conscious control as smooth, automated and highly integrated patterns of behaviours (Rasmussen, 1983). The perceptual motor system acts as a multivariable continuous control system synchronising the physical activity such as navigating the body through the environment and manipulating external objects in a time-space domain. The behaviours of this pattern are rare and only for slow, very accurate movements such as assembly tasks or drawing along without conscious attention or control. The information is perceived as *signals* which have no “meaning” or significance except as direct physical time-space date. The performance at the skill-based level may be released or guided by value features attached by prior experience to certain patterns in information not taking part in time-space control but acting as cues or *signs* activating the organism, referred to as *percepts* (Rasmussen, 1983).

The rule-based behaviour represents a sequence of subroutines in a familiar work situation, and is typically controlled by a stored rule or procedure which may have been derived empirically during previous occasions, communicated from other persons’ know-how as instruction or a cookbook recipe, or it may be prepared on occasion by conscious problem solving and planning. The rules may have been learned as a result of interacting with the plant, through formal training, or by working with experienced process workers (Embrey, 2005). The goal of the task only will be reached after a long sequence of acts, and direct feedback correction considering the goal may not be possible. The information perceived as *signs* which activate or modify predetermined actions or manipulations. Sign refers to a situation or behaviour in the environment, or to a person's goals and tasks or *action.*

The knowledge-based behaviour pattern happens when faced with the unfamiliar environment for which know-how or rules for control are available from previous encounters. In this environment, the human carries out a task in an almost completely conscious manner. This would occur in a situation where a beginner was performing the task or when an experienced individual was faced with a completely novel situation. The goal of the task is explicitly formulated by an analysis of the environment and the overall aims of the person. Informations are perceived as *symbol* which refer to concepts tied to functional properties and can be used for reasoning and computation by means of a suitable representation of such properties. Symbols are defined by and refer to the internal conceptual representation which is the basis for reasoning and planning.

Fitts (1962) distinguishes these three phases as: the learning or cognitive phase, the intermediate or associative phase and the final or autonomous phase. While Whitehead (1985) represents these behaviour phases as instinctive action, reflex action and symbolically conditioned action. Rasmussen stated that the development and models of human performance are useful to create a new interface system such as the implicit interaction in the ubiquitous computing environment. For that purpose, he suggested both qualitative and quantitative models of human performance are required to match categories of performance to types of situations. Numbers of detailed and preferably quantitative models which represent selected human functions and limiting properties within the categories while the role of qualitative model will generally be to guide overall design of the system structure. However, a major difficulty is the modelling of the knowledge-based control of performance during unfamiliar situations as well as the interaction among the different levels of performance depending upon the state of training. He also argued the need for human performance analyses in real-life situations to identify mental strategies and subjective performance criteria which can be through observation, interviews, verbal protocols, error report, etc which may lead to the description of actual performance or prototypical performance.

2.6 System Failure in the Ubiquitous Environment

While many researchers build advanced, complicated and elegant digital kitchens, fewer studies focus on the effect of task performance when a system failure happens. What is the effect on human performance when the environment fail to understand their requirement and needs, or when the technologies itself failed, such as when failing cues or interruption happened. Without doubt, ubiquitous computing radically increases the “failure” frequency compared to a wired distributed system. These are not literal failures but unpredictable events from which it is similarly complicated to recover (Kindberg, 2002). A number of works have been done typically to support the robustness of ubiquitous computing in terms of technical structure (LaMarca, 2002; Santoro, 2007; Gochhayat, 2012), however less works were done in understanding human performance when failures occurred specifically in a real ubiquitous environment. For that reasons, we explore interruption of task as the basic concept of understanding system failure. Mandler (1964) defined interruptions as an integrated or organised response sequence that produces a state or arousal which will be followed by emotional behaviour. He suggested that when the interruption is relevant to the sequence it produces less disruption; more nearly completed sequences are less disrupted than those just newly initiated.

Researchers from a variety of fields have explored task interruptions, ubiquitous occurrences in everyday human computer interaction in the context of the real-world task domain (Iqbal, 2005; Cutrell, 2000; Speier, 1999;). The complexity of the context of the interrupted task in applied domains often makes memory-based accounts difficult or implausible, whereas the task context for a simple experiment may involve only one or two memorised items. In order to study the effect of task performance on system failure; both the human interaction and psychology perspective have been reviewed.

Iqbal and Bailey (2005) investigated the effects of interrupting users at the 'best' and 'worst' possible points of interruption in the route planning and document editing task. From the work, they found that in the route planning task, the best interruption timing was between completing the second route and selecting the shorter route, while the worst interruption time was between finding information about the next trip and entering it into a table. Meanwhile, in the document editing task, the best interruption time was between completion of the last edit and saving the document and the worst interruption time was between placing the cursor at editing point and typing.

Bailey et. al. (2000) found that users perform slower on a task when interruption occurs than in the non-interruption condition, however the effect of interruption differs as a function of task category (Bailey et al., 2000). Adamczyk and Bailey (2004) demonstrate the timing interruption will give a different impact on the user's emotional state and recommended a system that could maintain the user's level of awareness while mitigating the disruptive effect of interruption (Adamczyk and Bailey, 2004). From the study, they show the effect of interruption on a computerised cleric and found that the operation time is increased when the operation is interrupted and there is additional activity after completion of the secondary task.

Meanwhile, Tran and Mynatt (2002) introduce the Déjà vu display as a resource for cooking 'memory' when interruptions occur. They report an experiment in which 16 participants prepare cookie dough in the 'aware' kitchen. Participants were told to expect an interruption (e.g. leave the task to get candy, talk to a friend, mop up a spilt drink or change the channel of

TV). Self-evaluation was issued after the interruptions. Findings from this study showed interruptions during the activity does affect the cooking process and participants make more mistakes such as adding too much salt or flour after the interruptions happened (participants did not remember the amount of ingredients added before the interruptions happened). The self-evaluation questionnaires showed that most of the participants found the *cook collage* is not helpful (no (5 participants); not really (3 participants)) but not distracting (11 participants). Participants who have higher memory skills suggest that they do not need help from *cook collage* while some have trust issues with the *cook collage.*

Though task interruptions are the most common occurrences in the human-computer interaction, interruptions can cause serious task completion issues which cause the scheduled task to stop responding to a stimulus. Roda (2011) indicates that the time span between a notification and the actual task switch, together with the associative cues provided by the system have a significant impact on task resumption. Once they resume the task, they may struggle to mentally reconstruct the status of the interrupted task, and may increase error rates. Dodhia and Dismukes (2009) examine three features of interruptions that may account for these failures; (i) interruptions often abruptly divert attention, which may prevent adequate encoding of an intention to resume and forming an implementation plan, (2) new task demands after an interruption reduce the opportunities to interpret resumption cues and (3) the transition after an interruption to new ongoing task demands is not distinctive because it is defined conceptually.

2.6.1 Trust in the Ubiquitous Environment

Now, we have looked at ubiquitous computing generally and the impact of system failure toward human performance, which we believe are closely related to 'trust'. In such a world, when computers move from big desktops and support seamless integration, there is need for a continuum of trust, which models the real world, as closely as possible. Trust is a particular level of the subjective probability with which an agent will perform a particular action, both before we can monitor such action or (independently of his capacity of ever to be to monitor it) and in a context in which it affects our own action.

Langeheinrich (2003) believed that trust is the vehicle for collaborating and socialising in the ubiquitous computing environment. Shankar and Arbaugh (2000) argued that there is a need for newer models of trust for the world of ubiquitous computing by representing trust in a realistic fashion, where people and devices trust each other to varying degrees and extents. Skankar and Arbaugh proposed an entity's *physical context* and *unified model* to represent trust relationships between entities. Trust in computing is widely acknowledged by the term trust management (Robinson, 2005) which enables systems to exchange information even without the intervention of administrators to authorise. The concept of trust management is about to grant users access to resources and information based on their trustworthiness rather than the application of conventional techniques that map authorisations to access rights. The view of trust in the ubiquitous computing environment measures how much resources or what types of information are permitted or would be disclosed to others (Robinson, 2005). Number of trust management system for ubiquitous computing are promising and encouraging but little is mentioned about implementation of these models and their validation, which would be necessary for their adoption (Bellotti, 1993; Cahill, 2003; Denko, 2011;Iltaf, 2012). Denko et. al (Denko, 2011) investigated their proposed probabilistic trust management which is capable of (1) allowing a device to judge the trustworthiness of another device it interacts with, while making a better use of the received recommendation and (2) behaving as expected when a device has little or enough experience of interactions with other devices. Meanwhile Iltaf et. al (2012) present a fully distributed framework that enables trust-based cloud customer and cloud service provider interactions. They developed a mechanism for controlling falsified feedback ratings from iteratively exerting trust level contamination due to falsified feedback rating. Trust expresses the level of access to resources that can be granted based on the available information and evidence. Therefore for trust management to be effective, the contextualisation of trust is an import step to build an appropriate level of trust in others. Consistent with this review of trust, trust has also become the main concern when there is an incompatibility display in the environment which will be further explained in Chapter 3.

2.7 Conclusion

The concept of ubiquitous computing is a 'great idea' that has evolved with many elements from ergonomics, human computer interaction, behaviour based knowledge, and advanced technology architecture. In this chapter, we have introduced ubiquitous computing from the perspective of human-computer interaction, which has been defined as involving *implicit* interactions, and its potential impact on human performance. This chapter provides the foundation for understanding *ambient display*. The chapter also provides a summary of the cueing effects, which might be critical in the potential use of ambient display. Further, work is explored on the impact on human performance of system malfunction, which is closely related to trust in the ubiquitous computing environment. A summary of this chapter's reviews are illustrated in Table 2.1.

Now that we understand the concept of Ubiquitous Computing and its component, *ambient display*, and how both elements related to each other in the digital environment, the questions are; how interaction can be achieved when the technology is hidden, how can ambient displays be integrated in the digital environment, and in what form or structure. Therefore, we suggest the concept of Stimulus-Response Compatibility (SRC), a useful theory apply in the environment. SRC studies the person's perception of the 'natural' interaction by considering relations between display (stimuli) and controls (response). When the relation between stimuli and response is direct, it is described as compatible by providing direct mapping manipulation. By contrast, when the relation is indirect and unnatural, it is described as incompatible. Chapter 3 will further explained this concept through the mapping of control and display in the stove top configurations and the potential role that ambient display might play in SRC.

Table 2.1 Thesis Theoretical Basis Overview

Thesis Theoretical Basis	**Overview.**
"Ubiquitous" in Human Computer Interaction	The theoretical basis of the thesis starting by understanding the concept of 'ubiquitous' computing interaction from the perspective of Human-Computer Interaction (HCI) which defined it as *implicit* interaction. The work will review the differences between traditional GUI and implicit interaction which then included some of the earlier works of the concept such as DigitalDesk, DigitalDesk Calculator, ClearBoard and continue with current work of ubiquitous such as EnhancedDesk, ProactiveDesk and The Reading Desk System..
Ubiquitous Computer	The concept of ubiquitous computing is explained to understand its philosophy, theory, and aims defined by Weiser and broadly defined by other researchers. The reviews help understand the emerging concept of implicit interactions within physical environments. The views look briefly into the concept of ubiquitous computing in today's environment before continuing with the earlier research works such as ParcTab, Classroom 2000, Cyberguide, Domisilica. The reviews then included works from Horizon, Newcastle Culture Lab (Balance@Home), and UbiComp Lab from the University of Washington.
Ambient Display	Extending the theme of ubiquitous computing, *ambient displays* are explored by understanding the concept and its implementation together within ubiquitous computing environments. A number of definitions of 'ambient display' are explored broadly from different researchers' perspectives. The work then reviews simple and complex ambient displays. Simple ambient display include works

	using simple physical tools or equipment, while complex ambient displays consider works that have complex arrangements. Furthermore, the work explores the effects of redundancy, multiple and failing cues in the ubiquitous environment.
Smart Kitchen Environment	Once the important element has been reviewed, the work then evaluates some of the work that uses domestic kitchen environment as an area of interest to be explored with ubiquitous and ambient displays. The smart kitchen environment has become a popular focus of attention for development, pioneered by MIT then followed by other research groups such as Smart Kitchen Minoh Laboratory and IBM Smart Kitchen.
The Impact of Culture in Ubiquitous Computing	As the work in this thesis will be looking into responses of different cultures in cooker-control, it is necessary to have overviews of cross-cultural research from the perspective of human-computer interaction. This work seeks to understand the intersection of culture and technology adoption. Cross-cultural studies have made direct links between culture and related preferences but with a high emphasis placed especially on behaviour.
Skills, rule and knowledge based behaviour	Another important element to be understood when designing the ubiquitous environment is the user's behaviour when interacting in ubiquitous environments. The arguments are to recognise the rule of human behaviour in the ubiquitous computer interaction.
System Malfunction	While most of the work in current research described the ubiquitous environment as the sophisticated and seamless environment which tries to improve HCI, few studies have been done to discover the potential of technology failure in the

	ubiquitous environment. The analyses look into users' behaviours, perspectives and reactions as different ranges of system malfunction occur such as interruptions and failing cues. The implication then is that trust is closely related to the interactions between users and objects.
Stimulus-Response Compatibility (SRC)	Another important element in this thesis which is closely related to ubiquitous is stimulus-response compatibility. The reviews explore the SRC concept, theory and principles, such as the simon effect, spatial compatibility, mode compatibility and others. Then the work reviews SRC in a classic cooker-control layout mapping with direct mapping and manipulation. The work also will look into some of the SRC effects and cueing effects. This review will further explained in Chapter 3.

CHAPTER 3
Ambient Cueing in Cooker Controls

Advances in devices for kitchens promise to provide new forms of digital interaction. As the concept of the digital kitchen becomes widely discussed, we believe it is worth looking back to the first approaches to understanding perceptions and performance in the kitchen. In order to relate these developments to Ergonomics, the principles and concepts of stimulus response compatibility (SRC) and its association with cooker-control is explored.

The stimulus-response (S-R) pairings refer to the spatial arrangement of controls and their associated display (Sanders, 1992, Sanders and McCormick, 1992). S-R pairings are commonly used not just for the arrangement of burners and controls on stove but also the arrangement of information on a monitor and the arrangement of the pilot cockpit (Chapanis and Lindenbaum, 1959, Fitts and Seeger, 1953a, Ray and Ray, 1979, Sanders and McCormick, 1988).

The concept of SRC is that when the relation between displays (stimulus) and controls (response) is direct, reaction time is fast because the user does not need to mentally translate from stimulus to response. Thus, a compatible response feels 'natural' because there is no need to mentally calculate which response is required. In contrast, an incompatible response occurs when there is no direct relation between stimuli and response. For example, four burners, arranged in 2 x 2 layouts are compatible when the controls are also arranged in a 2 x 2 pattern; it is obvious which control operates the corresponding burner. However, if the controls are arranged linearly there is no obvious spatial relation between the controls and burners, which may lead to selecting wrong control. Figure 3.1 shows illustration of these 2 x 2 burner and control layouts.

Figure 3.1 Layout of 2 x 2 control and burner with the left (L) figure is compatible arrangement control-burner and the right (R) figure is incompatible arrangement control-burner.

3.1 Concepts of Stimulus-Response Compatibility (SRC)

The established terminology, major findings and theoretical views concerning compatibility effects were formalised in two classic studies by Fitts and Deininger (1954) and Fitts and Seeger (1959). The concepts have focused on understanding the concept of perception-action relations.

Fitts and Seeger (Fitts and Seeger, 1953b) investigated the performance of an eight-choice-reaction task in which one of two styluses were moved from a home key along a pathway to a response location. Their work emphasized the transformation of information and their important finding showed that human performance is not only affected by characteristics of the stimulus set and response set used in the task, but also by the combination of these sets. Results from Fitts' work suggested that the more complex the set of stimuli, the more difficult it is for a user to respond and the greater the likelihood of errors. Their work also suggested that responses were faster and more accurate when the configurations of the stimulus and response panels corresponded than when they did not. Fitts and Deininger (1954) demonstrated compatibility effects as a function of mappings of individual S-R pairs within the same S-R sets. Furthermore, within each S-R set, performance was best with the maximal mapping, intermediate with the mirrored mapping and worst with random mapping. Their results indicate that the cost of incompatible mapping is greatest when the S-R sets also correspond (Fitts and Deininger, 1954).

Several authors (Fitts and Seeger, 1953b, Kornblum et al., 1990, Tipper et al., 2006) imply that compatibility gives affects to the performance of affordances in physical environment. It has been proved that the compatibility-affordance relationship is higher when there is commonality, similarity or correspondence between the stimulus and response sets. The higher the similarity of the SR set the greater compatibility will be and will result in faster response times, faster learning, fewer errors and reduced mental workload. Kornblum, Hasbroucq and Osman (1990) emphasised the distinction originally made by Fitts and Deininger (1954) between two determinants of S-R compatibility for which they coined the terms *set-level* and *element-level*. *Set-level* compatibility manipulation involved different pairings of stimulus response and sets, typically with the most compatible mapping of the individual stimuli and responses. *Element-level* compatibility involved differences in performance within the same stimulus and response sets as a function of the mapping of the individual stimuli and response (Proctor and Vu, 2012). They found that spatially corresponding mapping of left stimuli to left responses and right stimuli to right responses yields better performance.

3.1.1 S-R Compatibility with Irrelevant Information

Motivated by the compatibility work by Fitts and Seeger (1953), J.R.Simon conducted a series of studies investigating compatibility effects that occur when stimulus location is irrelevant to tasks but the responses are defined along a special dimension. In the 1960s, J.R. Simon conducted a series of studies investigating compatibility effects that occur when a non-spatial stimulus attribute indicates the correct response, whereas the spatial position of the stimulus is not task- relevant/attentional (Simon, 1990). Simon and Rudell (1967) tested two groups of participants; a younger group (aged between 18 and 25) and an older group (aged between 65 and 86). Their task was to respond to the spoken words *left* and *right* with a left or right key press, respectively. The words were presented over headphone to the left or right ear, but location was irrelevant to the task. The results showed that the left response was 39ms faster when the word *left* occurred in the left ear than when it occurred in the right ear, and the right response was 44 ms faster when the word *right* occurred in the right ear. The results revealed significant differences in response times (RT) as a function of age, sex and S-R correspondence (Practor and Phuang, 2006, Zorzi 1995, Simon, 1990). Irrelevant information cues are also referred to as the spatial Stroop effect (Simon, 1990).

The Simon Effect also occurred when the relevant visual dimension is in geometric form (Nicolleti and Umilta, 1989), letter identity (Proctor and Lu, 1994) and bright versus dim stimulus intensity (Proctor, Lu and Van Zandt, 1992). The Simon Effect obtained with visual stimuli is usually smaller (typically in the range of 15 to 30 ms) while with auditory stimuli it is in the range of 40 to 60 ms. Simon and Craft (1970) proved that visual stimulation in left-right locations did not produce a Simon Effect and suggested that an anatomical difference in the eye stimulated is not sufficient to yield a Simon Effect, but rather that the stimuli must be perceived and coded as being at a distinct location for an effect to occur.

There has been much research into this issue of compatibility, and Prector and Vu (2012) summarised the principles of compatibility.

- **Spatial compatibility** - compatible mapping of stimuli assigned to their spatially corresponding responses typically yields a better performance. This occurs when the mapping of stimuli to responses can be characterised by a rule or relation rather than when it is random.
- **Movement compatibility** - The motion of the display should be in the same direction as the motion of the control. Clockwise movement is used to indicate upward movement or an increase in magnitude of display.
- **Proximity compatibility** - Controls should be placed closest to the display they are controlling. Controls and displays should be arranged in groups corresponding to functionality and should be sequentially arranged.
- **Mode compatibility -** Better performance occurs when there is match between display and control models (visuospatial-manual and verbal-local) than where there is not. There is less interference from irrelevant information when it is conveyed by a stimulus mode different to the mode used for relevant information.

The concept of SRC which has been reviewed in this section has many basic and applied implications for human information processing and performance. Overall, compatibility effects have been found to influence performance in a variety of situations. Consequently, the next sections will be looking at compatibility in the stovetop configuration.

3.2 Spatial Compatibility and Cooker Burner Controls

The cooker-control studies reveal differences in approach that occur in measuring compatibility. These approaches include using a questionnaire approach (paper-pencil test) (Shinar and Acton, 1978, Hsu and Peng, 1993, Wu, 1997), prototypes of cookers (Chapanis and Lindenbaum, 1959, Ray and Ray, 1979, Wu, 1997) or computer simulation (Hsu and Peng, 1993) to explore users' preferences in cooker-control linkages. Figure 3.2 illustrates the arrangement of cooker and burner used in the studies by Chapanis and Lindenbaum (1959), Shinar and Acton (1978) Payne (1995), Wu (1997), and Tlauka (2004).

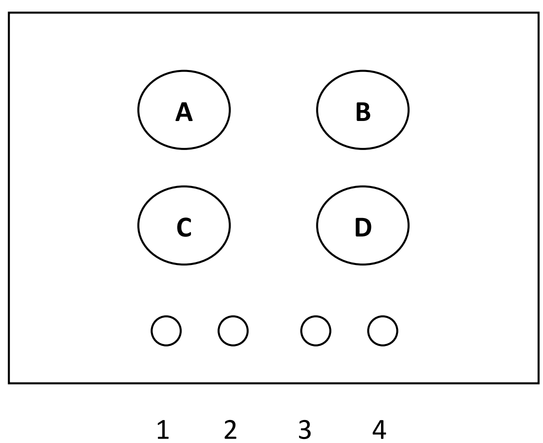


Figure 3.2 Arrangements of cooker and controls used in studies by Chapanis and Lindenbaum (1959), Wu (1997), Payne (1995), Shinar and Acton (1978) and Tlauka (2004).

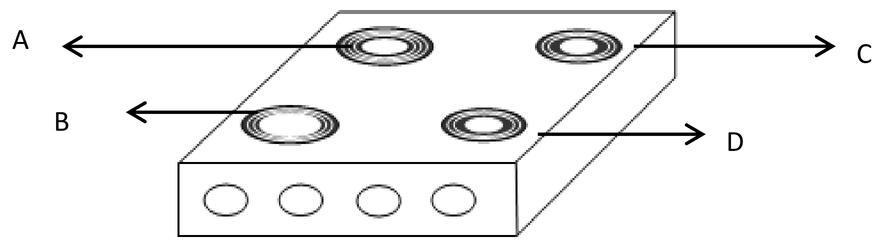
Differences have been found in the arrangements of burner and controls that people consider the best and those with which they actually perform best (Hoffman and Chan, 2011). 'Best' here means that the users made fewer errors or had a shorter reaction time in using the device.

3.2.1 Paper-Based Studies of Cooker Controls

The first work exploring preference in cooker-control layout using a paper-based questionnaire was by Shinar and Acton (1978) who presented participants with a drawing similar to Figure 3.3 and asked them to label the unmarked controls with the letter which they thought indicated the ‘correct’ control for each burner. Findings from this study showed at least four commonly expected linkages: Linkages II, III, IV and V. Linkage III was chosen by 31% of the participants, while Linkage II was chosen by 25%. However, there was not a sufficiently strong preference to be considered as a popular stereotype.

Hsu and Peng (1993) reported preference for cooker-control linkages through various forms of labels to test whether a suggestion effect existed in the sequential nature. Their study compares alphabetical (ABCD), code (# △ □ ☆) and numerical (1234) labelling in a cooker controls questionnaire. They showed that Linkage II was preferred

Wu (1997) also reported comparisons of preference for linkages in cooker controls using two forms of labels; alphabetical and sign. Consistent with Hsu and Peng’s results, the results of Wu's study showed that Linkage III was preferred when participants were presented with the alphabetical labels and Linkage II was preferred with the sign layout. This implies that the manner in which the controls are labelled has an impact on the interpretation of the order in which the controls are operated, which affects the perception of the arrangements of the burners.



Type	Control Cooker Arrangement
II	A B D C
III	A B C D
IV	B A D C
V	B A C D

Figure 3.3 Control-burner arrangements studies by Shinar and Acton (1978)

Tlauka (2004) tested the usability of cooker control mappings using several types of stimuli ranging from simple shapes to semantic stimuli. By giving a paper-pencil test questionnaire, 88% and 92% of participants (Studies 1 and 2 of Tlauka) gave the 'correct' response of cooker controls when burners were displaced sideways in such a way that controls were directly below the corresponding burner; this result was consistent with Linkage I from the Chapanis and Lindenbaum study. While Chapanis and Lindenbaum (1959) showed that Linkage II was the second most preferred linkage, only 34% and 28% (Studies 1 and 2) of participants from Tlauka's studies selected this response.

This selection of studies indicates that there is no clear-cut response from participants in these pencil-and-paper tests. Overall, Linkages II and III appear to be preferred over the other layouts. For some researchers, the problem lies in the ambiguity of the cues that are provided and so have explored other forms of cue to help people make their selection of linkage.

3.2.2 Sensor Lines and Other Additional Cues

The problem with the ‘standard’ four burner stove (Figure 3.2) lies in the spatial relationship between controls and burners. However, this problem does not occur when there is geometric similarity of burners and controls (Hoffmann and Chan, 2011). This is the very basis of SRC – if there is an obvious relationship between the control and the object that is being controlled then the user will ‘automatically’ select that control. The previous section suggested that adding labelling can interfere with this naturalness by requiring the user to ‘translate’ from the presented information to the control selection. Therefore, a number of studies have proposed the use of additional spatial information. For example, ‘sensor lines’ can be drawn from a control to the burner to which it is linked.

Chapanis et al. (1965) tested the effectiveness of sensor lines in two different size layouts (4 lights and keys, 8 lights and keys) with compatible and incompatible arrangements. Sensor lines in the compatible arrangement appeared to hinder rather than help and only served a useful function of sensor lines in the large panel if there was an incompatible arrangement of cooker and controls.

Osborne et al. (1987) measured reaction times and errors to examine the utility of sensor lines. Four cooker controls layouts types were tested; displaced burners (Linkage I), standard arrangement (Linkage II) and two cooker layouts that either had partial or complete sensor lines. The results showed the displaced burners to be superior in both reaction time and errors, followed by complete sensor lines, then partial lines and finally the standard layout. Chapanis and Yoblick (2001) placed ‘sensor lines’ painted on the stove top to indicate the linkage between cooker and controls. Performance on incompatible panels with sensor lines was significantly poorer than on the same panels without sensor lines. This suggests that simply adding sensor lines does not guarantee improved performance on incompatible displays, and does not seem to help compatible arrangements either.

3.2.3 Spatial Compatibility with Physical Stove Models

Several studies have investigated the physical arrangements of cooker controls on physical models of four burner stoves. Chapanis and Lindenbaum (1959) used a wooden model of a stove (18in x 24in x 6in) to measure reaction time and errors in selection of controls with different linkages. The results showed reaction times to Linkages III and IV were about the same and slower than Linkages I and II. 105 errors were made in Linkages III and IV, 6% in Linkage II and no errors in Linkage I. This suggests that, contrary to the results from paper-based studies and sensor-lines studies (which implied a preference for Linkage III), Linkage I would appear to be preferable.

Ray and Ray (1979) used a cooker control simulator to control ‘in line’ and ‘quadrant’ cooker control layouts as illustrated in Figure 3.4. The results revealed no errors with the ‘in line’ arrangement and the most errors in the ‘quadrant’ cooker control was in Linkage IV (which they termed A3) (19.2%), followed Linkage III (A2) (16.3%), then Linkage VII (A1) (12.2%) with Linkage II(A4) producing the fewest errors (8.6%).

Hsu and Peng (1993) used a computer simulator to test four types of cooker control linkages; Types II, III, IV and V. The task was to turn off a light by pressing the ‘correct’ key as quickly as possible and if errors were made, participants were required to press another key until the correct one was found. Results showed that Linkage III was the preferred arrangements with response times being 0.63s and 4.33% of error rates. This is contrary to the earlier studies and more in accordance with the paper-based studies. However, it is suggested that clicking on the computer screen is, perhaps, similar to circling an option on the paper-based questionnaires – and so one might expect similar results.

Motivated by previous studies, Wu (1997) measured reaction times and errors using a wooden four-burner model with a dimension of 46cm wide, 61cm long and 15cm high. Coloured perspex discs were used for burners, illuminated by small LEDs. The controls were push buttons – fitted on the front vertical panel for the stove. The circuits were arranged so that one of the burners could be lit automatically by a computer and turned off when the participant pressed the correct control. A timer ran in the computer and served as the measuring instrument. The results of this study showed that, for Chinese participants, Linkage V was the preferred arrangement with response times 0.64s and 2% of error rates while Linkage II was preferred by American participants with response times 0.69s and 2.5 % of error rates. A summary of findings from previous studies is shown in Table 3 .1.

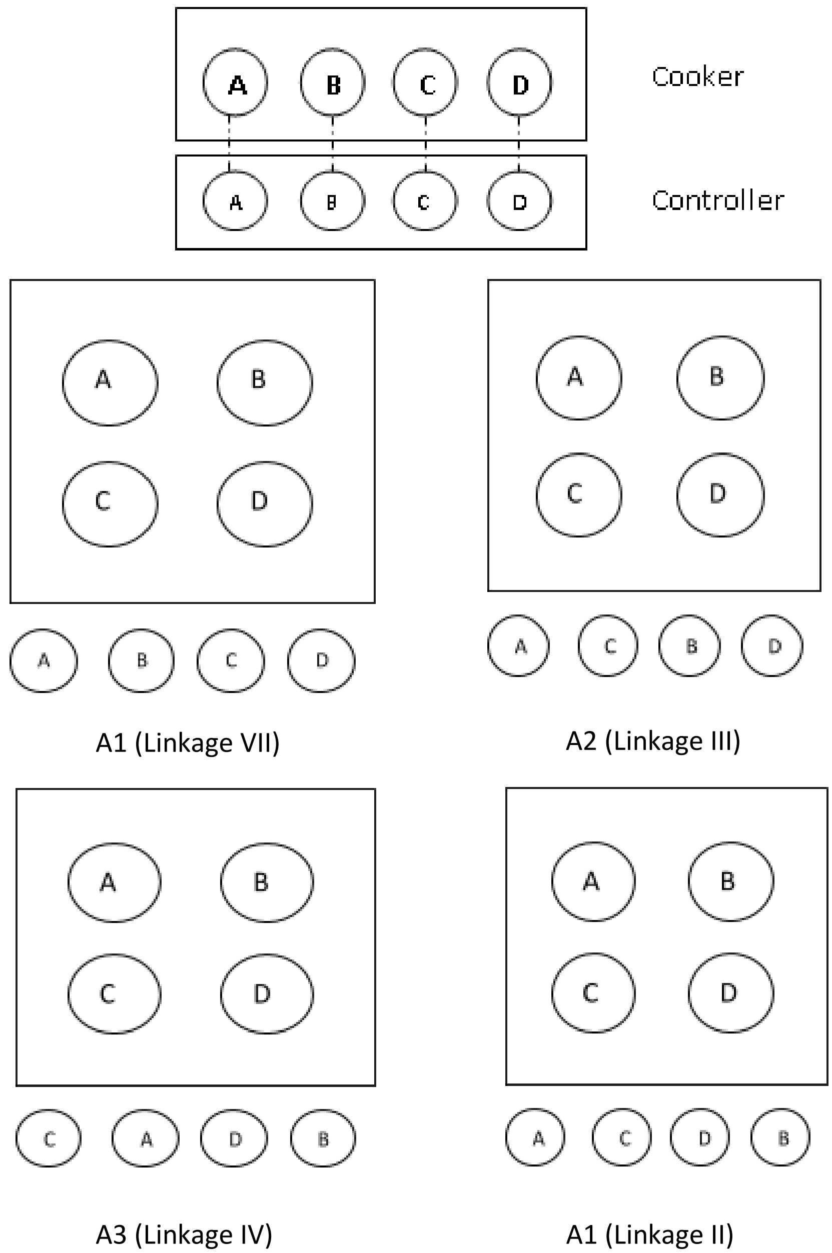


Figure 3.4 Illustration of cooker control layouts by Ray and Ray (1979)

Table 3.1 Comparisons of reaction times and error rates from previous studies

Types	Linkage Relationship	Chapanis and Lindenbaum (1959)		Ray and Ray (1979)		Hsu and Peng (1993)		Wu (1997)	
		Reaction Time	Error Rate (%)	Reaction Time	Error Rate (%)	Reaction Time	Error Rate (%)	Reaction Time	Error Rate (%)
II	ABDC	-	**6***	-	**11***	0.665	11	0.699	2.5
III	ABCD	-	10	-	4	**0.631***	**4***	0.693	3.3
IV	BADC	-	11	-	10	0.715	10	0.704	3.7
V	BACD	-		-	11	0.720	11	**0.637***	**2.0***

The preferred arrangement for the study

Motivated by the sensor lines studies, we believed that digital interaction can be achieved when there is compatibility of the projected ambient display in the digital environment. This is the starting point for this research. Rather than using sensor lines, the study employs light (following the design proposed by Wherton and Monk (2009) shown in Chapter 1). This study considers whether the use of such simple ambient displays could provide sufficient cueing to allow people to respond effectively in control – burner selection tasks.

The provision of additional information, such as sensor lines, changes the nature of both the product and the task. Rather than responding to compatibility, this additional information creates the need to be interpreted in order to follow cues. While some forms of ambient display could be projected to offer such cues, the issue remains whether this modification of product or environment constitutes a change to the demand of the task. The challenge for ambient displays is to find ways of adorning the world with subtle forms of display that leave the environment to all intents and purposes unchanged in comparison to its previous state. Ideally, the displays would exist at the edge of awareness and be barely noticeable, rather than be glaring, conspicuous and have obvious modifications. This means that the ideal ambient display would support the sort of automatic response that SRC assumes: as soon as the user either becomes distracted by the display or is forced to perform some form of 'translation' then the effectiveness of the display is diminished.

It is argued that the projected display which presents excessive or inappropriate information that interrupts or distracts the user from his/her task ceases to be 'ambient'. Furthermore, the use of projected displays can offer multiple sources of information to users, rather than a single set of sensor lines; for example, it is possible to present several cues to users at the same time. One would hope that additional information ought to improve performance. However, it might be possible for the ambient display to present conflicting information and a further objective is to consider whether confused information can impair performance.

For the purpose of this study, a pencil-and-paper test was conducted prior to the construction of the physical hardware: if participants demonstrated confusion or uncertainty in the test, then it might not be sensible to proceed with building the physical prototype. While several papers (Liu and Khooshabeh, 2003, Hoffmann, 2009a, Hoffmann, 2009b) have argued that it is not clear if there is a benefit in using paper-pencil test for studying cooker control compatibility, we believe that a paper-pencil test is still an appropriate approach as the preliminary test in the cooker control compatibility with ambient cueing.

This balance of this chapter is divided into five sections. The design and hypothesis of the study will be discussed in Section 3.2 followed by the procedure of the experiment in Section 3.3. Analysis of the results will be discussed in Section 3.4 and the discussion of the finding of this experiment in Section 3.5. Section 3.6 will conclude the overall aims, method and findings in this study.

3.3 Design and Hypotheses

In the questionnaire used in this study, three coloured circles are used to indicate the different Light Emitting Diodes (LEDs) – red, blue and green – which are used to indicate cues. These cues differ from previous studies which used letters, numbers or signs to label the controls or sensor lines to show links from control to burner. We are not aware of any previous work using this form of coding.

The LEDs are intended to give a participant a sense of ambient display in the kitchen environment. In this experiment, the LEDs convey three types of cue to the user.

i. **Hob LED,** represented by a Red circle in this questionnaire, indicates whether a burner is lit. By using red LEDs we capitalise on the user's experience of burners on a hob. In this respect, we would expect the response to be similar to previous studies on SRC in cooker controls.
ii. **Hob-aligned LED (**Blue LEDs) mounted on the underside of the 'hood' (in case there is a pan on the burner). By using blue LEDs we create an additional source of information corresponding to the burners that are lit. This ought to simply be a reflection of the preference under Type I. However, the novelty of the positioning of these lights could cause confusion.
iii. **Control-aligned LED -** cueing the control to use represented by green LEDs mounted on the front of the 'hood' in line with the controls. By using green LEDs, we replicate

> the alignment of control with burner that has been previously achieved through offsetting the controls or by using sensor lines. The idea is that, when a burner is on, the corresponding control-aligned LED will come on.[2]

In order to test spatial compatibility, the questions were designed to present two variations of control-burner arrangement to participants: the response could be from a linear control-burner arrangement or from a quadrant control-burner arrangement. These control-burner arrangements were designed in the 3-dimensional (3D) perspective so that all the lights were aligned together and visible to the participant's view. Although paper-based design work is a justifiable method for working on concept designs, the limitations are more pronounced when simple 2D images are used. Therefore, a 3D perspective model of the cooker-burner arrangement is used to convey complex inter-relationships, which are otherwise difficult to visualize. The three LEDs (red, green and blue) can be easily understood and interpreted in 3D. The mapping between the cooker-burner and LEDs can be easily visualized from different angles. Additionally, it significantly reduces any ambiguity, making it more straightforward across the design intent and should lead to less misinterpretation. This was important so that the participant could understand and interpret the ambient cues given. The cooker-burner arrangement layouts of this study are illustrated in Figure 3.5.

[2] Of course, if more than one burner is on, then the relative benefits of this cueing could be reduced. This question of multiple cueing has not featured much in previous research on cooker-control compatibility and thus the studies in this thesis will concentrate on the challenge of selecting a single control to operate a single burner.

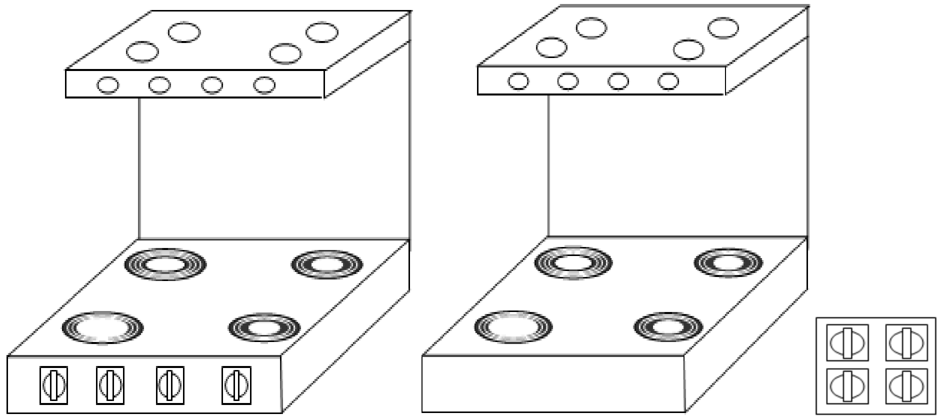


Figure 3.5 A schematic representation of the control-burner arrangement designs used in the paper-pencil questionnaire.

As noted above, the Red (R) LEDs are positioned on the hob (to indicate burners switched on), Blue (B) LEDs are positioned in the cooker hood (aligned with the Red LEDs on the hob) and Green (G) LEDs are positioned in a row on the cooker hood (aligned with cooker controls). The three LEDs were then combined with each other to generate six different combinations of ambient lights and questionnaires. The questionnaires employed the following ambient LEDs which linear arrangement is illustrated in Figure 3.6 and the quadrant arrangement is illustrated in Figure 3.7.

i. Compatible Red LEDs (R)
ii. Compatible Blue LEDs (B)
iii. Compatible Red + Green LEDs (CRG)
iv. Incompatible Red + Green LEDs (IRG)
v. Compatible Red, Blue + Green LEDs (CRGB)
vi. Incompatible Red, Blue + Green LEDs (IRGB)

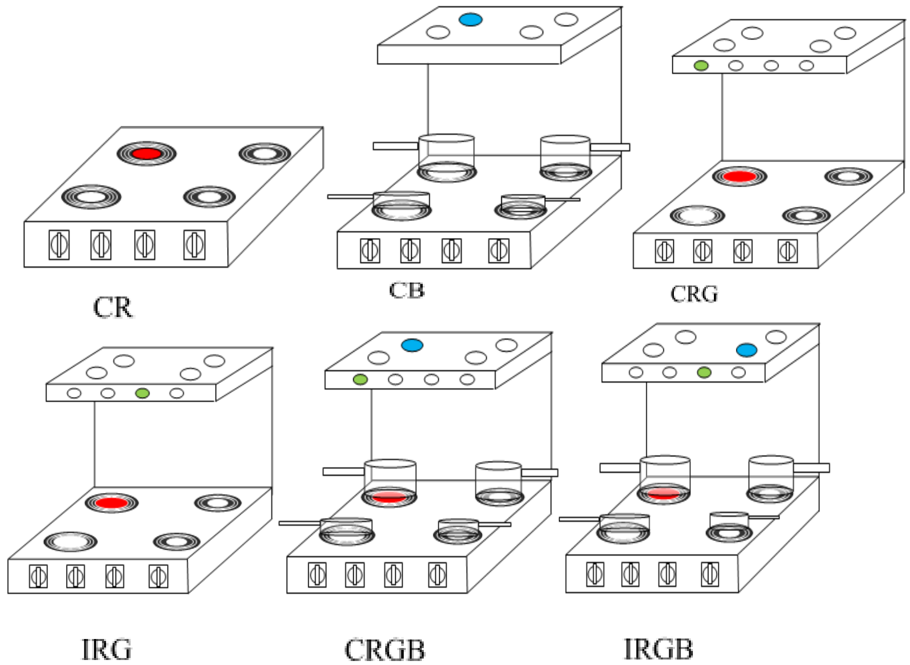


Figure 3.6 A schematic representation of linear control-burner arrangements in paper-pencil questionnaires.

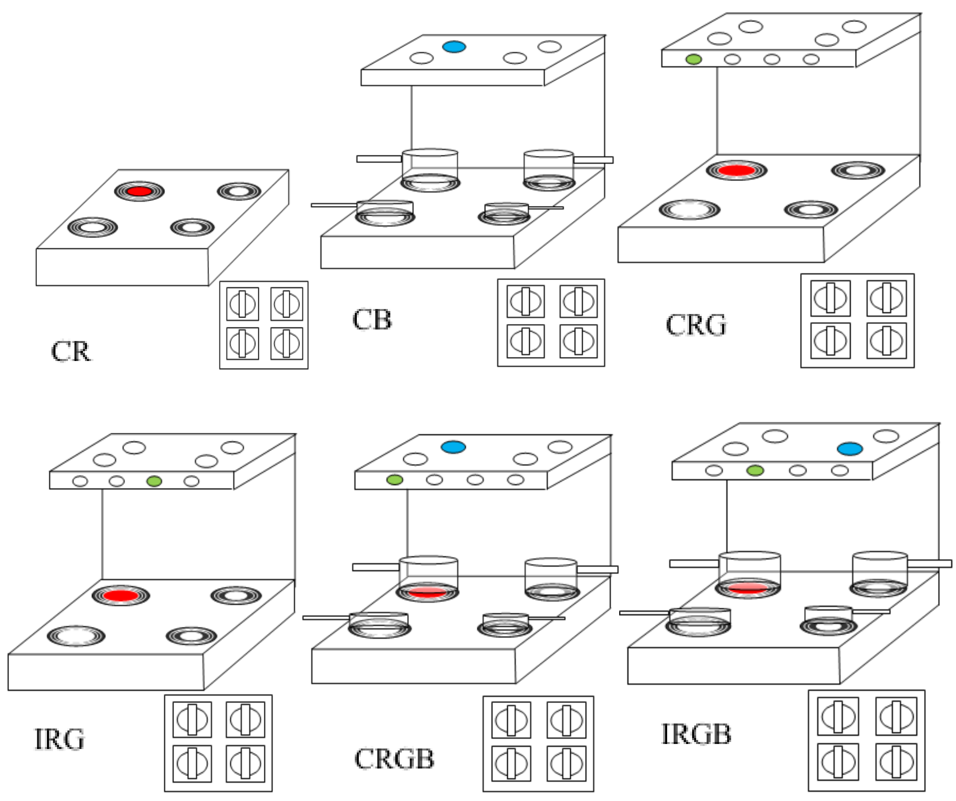


Figure 3.7 A schematic representation of quadrant control-burner arrangements in paper-pencil questionnaires.

While the designs were constructed on the assumption that Linkage III was the users' most preferred control-burner arrangement (because this was the main (although not only) layout that paper-based studies had previously shown), it is not essential that participants get the answer ‘correct’; rather, the responses are used to determine which of the linkages were most popular and whether there was any consistency in the responses. A set of these questionnaires can be seen in Appendix A and B.

Within these six questionnaires, two presented incompatible, and inconsistent, arrangements. Compatible arrangements refer to the combination of LEDs and controls that conform to the Linkage III and indicate if the LEDs provide the same response to a given control (if there is more than one LED). An inconsistent arrangement indicated that the LEDs create different responses. Given the fact that when using all 3 LEDs, it was only possible to have 2 types of arrangement, it was decided to apply this principle to the other combination. This means that for one and two LED combinations, it presents a subset of possible combinations rather than the full spectrum of combinations.

Each questionnaire therefore has four cooker-burners in different positions of ambient LEDs. A total of 12 questionnaires are given to participants with six questions concerning the linear rotary knobs arrangement (Figure 3.3) and another six questionnaires on the quadrant rotary knob (Figure 3.4). Therefore, each participant answered 24 different cooker-burner arrangements in linear rotary knob and quadrant rotary knob condition with a total of 48 four-burner layouts shown to participants.

The primary objective of this study is to explore how cueing can affect performance of simple tasks. One would expect that additional information ought to improve performance. However, it might be possible for the LEDs to present conflicting information and a further objective is to consider whether confused information can impair performance. Further, we assume that as the number of cues increases there is a potential for participants to become confused by the amount of information, particularly in conditions with inconsistent cueing. During the experiment, preference linkage choices were measured and the following hypotheses were drawn.

i. **Hypothesis 1 (H1): A c**onsistent response of preference linkages can be seen in all the quadrant cooker control arrangement scenarios due to spatial compatibility (direct mapping) between cooker and controller.
ii. **Hypothesis 2 (H2): The n**umber of responses in the linear cooker control arrangement layouts was varied as number of LEDs increased.
iii. **Hypothesis 3 (H3):** Linkage III becomes the predominant preference linkages in the single LEDs (as found from previous studies) compatible linear cooker control arrangements.

3.4 Participants and Procedures

This section explains the experimental task where participants need to answer the questionnaire given by choosing the correct rotary knob to respond to a given ambient light (or lights). Their choice was based on their preference.

25 university students were involved in the experiment. They were aged between 19 to 40 years with an average age of 23 years. 20 participants were male and 5 were female. Participants were recruited from different cultures and came from different degree programmes but all had a minimum of one year of experience in the kitchen environment and had used cookers. These experiences include a participant's familiarity to switch the cooker on and off or cook a simple dish, such as making an omelette.

By using a frequency or number of participants' responses to particular linkages, a Chi-Square statistical analysis was used to compare preferred linkages. Due to the relatively small number of participants used in this study, a Likelihood Ratio test was used to report the statistical analysis along with effect size (reported in the odds ratio). An odds ratio is used to summarise a focused comparison and a 2 x 2 contingency table is the categorical data which focused comparison. The odds ratio can be calculated as below. Chi-Square analysis results are reported in Appendix A.

$$\text{Odds}_{\text{numbers of participants choose linkage X}} = \frac{\text{participants who had chosen linkage X}}{\text{participants who did not chose linkage X}}$$

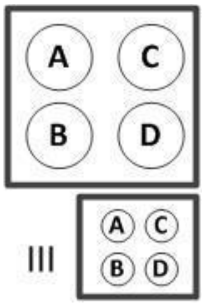
$$\text{Odds}_{\text{number of participants choose linkage Y}} = \frac{\text{participants who had chosen linkage Y}}{\text{participants who did not chose linkage Y}}$$

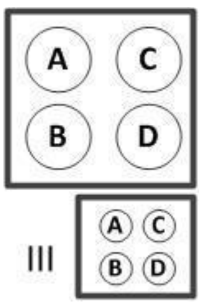
$$\text{Odds ratio} = \frac{\text{Odds}_{\text{number of participants who chose linkage X}}}{\text{Odds}_{\text{number of participants who chose linkage Y}}}$$

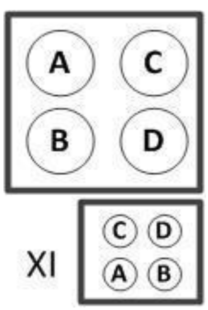
To control for order effects in this study, presentations of the questionnaires were randomised across participants using a Latin Square. Thus, each participant would get a different order of questions. Each questionnaire contained a question, ‘Which rotary knob would you use to switch off the light (s)?” The participants’ task was to indicate the answer by marking an ‘X’ for each cooker-control arrangement, and they were instructed to fill in the questionnaires with their first preference response.

3.5 Results

Tables 3.2 and 3.3 summarize the number of responses (and the percentage these represent) to each possible control-burner linkage arrangement made by participants in the quadrant and linear knob arrangements. The result shows that there is a large number of differences in participant responses between linear and quadrant knob arrangements.



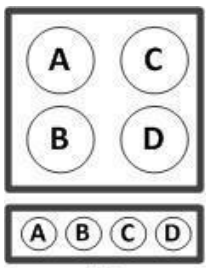




From Table 3.3, one can see the responses were consistent throughout the scenarios in the quadrant control-burner arrangement. Linkage III was clearly the most popular and preferred choice in the quadrant control-burner; 96% of participants selected Linkage III in the single Red LED scenario (CR); 88% participants selected Linkage III in the single Blue LED (CB) scenario; 96% participants chose Linkage III both in the compatible and incompatible Red-Green (CRG and IRG) LEDs scenario; 96% participants selected this linkage in the compatible Red-Green-Blue (CRGB) scenario, and 92% participants responded to Linkage III in the incompatible Red-Green-Blue LED (IRGB) scenario.

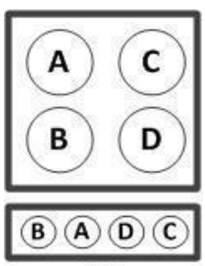
Table 3.2 also illustrates the results of the Chi-Square analysis of quadrant cooker-control arrangement. The number indicates number of participants responds to the linkage. For instance, 24 participants responded to Linkage III in compatible red scenario (CR), while the number within the parenthesis is the percentages represented. Letters in the curly brackets indicate linkage which differs from the one in the cell. For example, Linkage III is more significant to be chosen than Linkage XI in the compatible red (CR) scenario with $p < 0.001$.

This demonstrates that Linkage III is significantly the most preferred linkage compared to any other linkages when the cooker-control was in the quadrant arrangement.



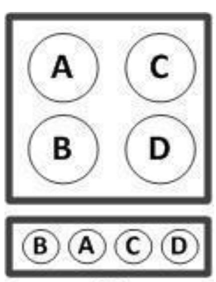
III

In contrast with the consistent response to the quadrant arrangement, the linear control-burner arrangement (Table 3.4), as one might expect, showed more varied results. For single Red and Blue LEDs in the compatible arrangement (CR and CB), a majority of participants selected Linkage IV (28%), followed by Linkage V (24%). Only 16% of participants selected Linkage III in these scenarios.



IV

For pairs of LEDs (CRG), Linkage III was the most preferred for 48% participants. In the incompatible Red-Green (IRG) scenario, 28% of responses were to Linkage IV, followed by 24% participants responding to Linkage XII. Linkage III was selected by only 8% participants in these scenarios.



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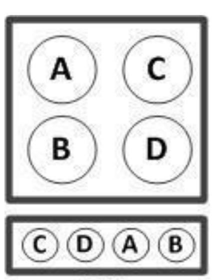
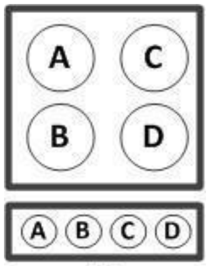


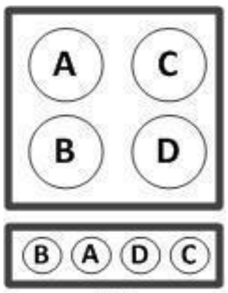
XII

For three LEDs, 52% participants chose Linkage III in the compatible Red-Green-Blue (CRGB) scenario. In the incompatible Red-Green-Blue (IRGB) scenario, Linkage V was the preferred linkage for 32%. Linkage III was selected by 8% participants. Chi-Square tests with a Likelihood Ratio analysis show that in the



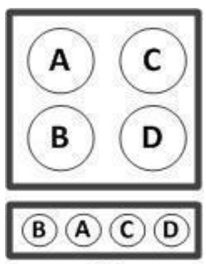
III

incompatible Red-Green (IRG) LEDs scenario, Linkage IV was chosen significantly more often than Linkage VII but with no significant difference to other linkages.



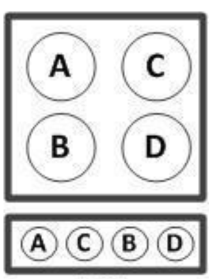
IV

In the compatible Red-Green-Blue (CRGB) LEDs scenario, Likelihood Ratio analysis results showed that Linkage III was chosen significantly more often than Linkages II, IV, V, VII and 'redundancy' linkages. The odds ratio shows that choice of Linkage III was 7.95 times higher than Linkage II, 5.68 times higher than Linkage IV and 2.6 times higher than Linkage VIII and 'redundancy'.

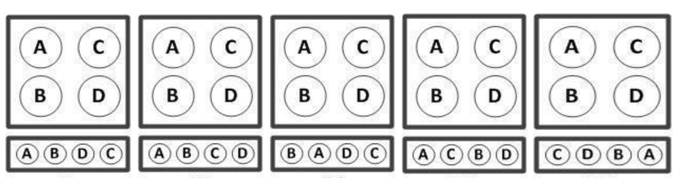


V

In the incompatible Red-Green-Blue (IRGB) LEDs scenario, Linkage V was chosen significantly more often than Linkages II, III, IX, XII, 'other' and 'redundancy' linkages. The odds ratio shows that the response to Linkage V was 5.41 times higher than Linkage II and III, 3.45 times higher than Linkages IV, VII and XIII and 11.31 times higher than Linkages IX, XIII, 'others' and 'redundancy'



VII



II III IV VII XIII

Table 3.2 Number of responses to quadrant knob arrangement in the paper-pencil questionnaires.

Linkage		**CR**	**CB**	**CRG**	**IRG**	**CRGB**	**IRGB**
II	ABDC						
III	ABCD	**24 (96)** **(Lei et al.)***	**22 (88)** **(Hommel, 1994)***	**24 (96)** **(Lei et al.)***	**24 (96)** **(Lei et al.)***	**24 (96)** **(Lei et al.)***	**23 (92)** **(Lei et al.)***
IV	BADC						
V	BACD						
VI	BDAC						
VII	ACBD						
VIII	ADBC						
IX	BDCA						
X	BCAD						
XI	CADB	*1 (4)*	*1 (4)*	*1 (4)*	*1 (4)*	*1 (4)*	*1 (4)*
XII	CDAB						
XIII	CDBA						
Others							
Redundancy (R)			*2 (8)*				*1 (4)*
	Total:	**25**	**25**	**25**	**25**	**25**	**25**

*p < 0.001, **p < 0.05, n.s = not significant
Number inside the parenthesis is a percentage
Redundancy is the number of participants who chose the rotary knob twice.

Table 3.0.3 Number of responses in linear arrangement in the paper-pencil questionnaires.

Linkage		CR	CB	CRG	IRG	CRGB	IRGB
II	ABDC	*4 (16)*	*4 (16)*	*4 (16)*	*4 (16)*	*3 (12)*	*2 (8)*
III	ABCD	*4 (16)*	*4 (16)*	**12 (48)** **{VII, R}*** **(Bakar et al., 2011)****	*2 (8)*	**13 (52)** **{VII, R}*** **(Bakar et al., 2011)****	*2 (8)*
IV	BADC	**7 (28)** **{II, III, V, O}$^{n.s}$** **{VII, R}****	**7 (28)** **{II, III, V, O}$^{n.s}$** **{VII, R}****	*3 (12)*	**7 (28)** **{II, III, V, XII, R}$^{n.s}$** **{VII}****	*4 (16)*	*3 (12)*
V	BACD	*6 (24)*	*6 (24)*	*3 (12)*	*3 (12)*	*3 (12)*	**8 (32)** **{II, III, IX, XII, O, R}**** **{IV, VII, XIII}$^{n.s}$**
VII	ACBD	*1(4)*	*1 (4)*	*1 (4)*	*1 (4)*	*1 (4)*	*3 (12)*
IX	BDCA						*1 (4)*
No responds in Linkages VI (BDAC) VIII (ADBC), X (BCAD) and XI (CADB)							
XII	CDAB				*6 (24)*		*1 (4)*
XIII	CDBA						*3 (12)*
Others		*2 (8)*	*1 (4)*				*1 (4)*
Redundancy		*1 (4)*	*2 (8)*	*2 (8)*	*2 (8)*	*1 (4)*	*1 (4)*
	Total:	**25**	**25**	**25**	**25**	**25**	**25**

*p*p < 0.001, **p < 0.05, n.s = not significant
Number inside the parenthesis is percentages
Redundancy is the number of participants that choose rotary knob twice.

3.6 Discussion

This chapter describes the preliminary work of designing digital interaction through a classic ergonomics approach using cooker-control layouts. The study tested 25 participants through a series of cooker-control questionnaires which evaluated the concept of ambient cueing using LEDs on the cooker. These questionnaires consisted of two types of cooker-control layout; linear and quadrant, and between the layouts there are compatible and incompatible arrangements.

The study examined whether the presence of additional information changed the nature of users' perceptions. Quadrant cooker-control layouts show that, regardless of the addition of information given, or the combination of two or three LEDs, or the arrangement of compatible or incompatible layouts, a high percentage of responses favour Linkage III. This was as expected in Hypothesis 1 (HI). This suggests that additional information does not help or change the nature of user decision-making in high spatial compatibility layouts (although it suggests that such arrangements need not be detrimental to performance either).

When participants respond to the linear control-burner arrangement the number of responses varies. This was expected in Hypothesis 2 (H2). It is interesting to note that Linkage III is not the predominant linkage for the single LEDs. This contradicts Hypothesis 3 (H3). Results show that Linkage IV is the dominant response and this is not consistent with previous findings.

Interestingly, the results show that Linkage III becomes the dominant preference when the number of LEDs increases from 1 to 2 or 4 LEDs (as long as the arrangement is compatible).

These findings suggest that, as the number of LEDs increases in the compatible arrangement, the response to Linkage III increases. A preference for Linkage III was significantly greater ($p < 0.05$) than Linkages II, IV and V, and then Linkage VII and 'redundancy' ($p < 0.001$), in the compatible two LEDs (CRG) and three LEDs (CRGB) scenarios. However, when LEDs are presented in incompatible arrangements, Linkage III is less likely to be selected. This result shows that when there are some inconsistencies in the relationship between stimuli, then the preference for configurations becomes more confusing; indeed, this confusion is further manifested in the increase in the number of different linkages selected in the incompatible Red-Green-Blue (IRGB) scenario. Therefore, it can be suggested that, as the number of LEDs increases in the incompatible arrangement, the consistency of responses reduces. This could indicate that the provision of additional information served not to complement but to confuse the perception of spatial compatibility.

3.7 Conclusions

The stimulus-response compatibility of four burner-stove layouts with quadrant and linear control-burner arrangement was investigated in this chapter by using a questionnaire method. This investigation aimed to identify linkage preferences of control-burner arrangements and perceive human perspective when additional information is given. Ambient lights with combinations of single, two or three LEDs are used in this study.

Section 3.4 illustrated the finding of this study and how Linkage III is not the dominant preference linkage in the single LEDs, in either the Red or Blue scenarios. But a higher number of responses to Linkage III can be seen when the number of LEDs increases from one to two or from two to three. There are varied responses when incompatible arrangements are given to participants.

In the next chapter, the linkage preference in four-burner layout is further discussed; taking into account the contrasting preferences of different cultures and demonstrating the population prototype of linkage preferences between British and Malaysian people.

CHAPTER 4

Population Stereotypes in Cooker Controls

The previous chapter introduced a classic ergonomics approach to the study of cooker control layouts, which involved the use of paper-based questionnaire to elicit preferences for cueing using multiple LEDs. Results from the questionnaire show that Linkage III is not a dominant preference for displays using a single LED in the linear control arrangement, but becomes more popular when the number of LEDs increases to two or three (but only in the compatible arrangement). In contrast, the quadrant control arrangement shows a consistent preference for Linkage III irrespective of the number of LEDs used and whether they were presented in compatible or incompatible arrangements.

In order to explore whether the findings from the questionnaires can be generalised across different cultures, this chapter uses the same questionnaire to compare responses to cooker control layouts between two cultures: Malaysian and British (residence of West Midlands of United Kingdom). This study measures cooker control layout preferences between these two cultures in order to consider whether it is possible to determine the population stereotypes of each culture in responding to cooker-control layouts, and the impact that additional cueing might have on these stereotypes. The stereotypical response is the one that is provided most frequently, and the percentage of individuals giving that response is an indication of the strength and stereotype. Prector and Vu (2012) indicated that certain stereotypes are due to spatial relationships that are inherent in interactions with the physical environment. However, other stereotypes of a function of experience and learning within a particular culture are therefore culturally specific, as explained in Chapter 2.

4.1 Stimulus-Response Populations Stereotypes.

Several studies have been conducted into population stereotypes in people's expectations on cooker-control relationships for stovetop configuration. Wong and Lyman (Wong, 1988) for example, compared preferred direction-of-motion relations of American and Japanese right-handed subjects for a vertical display and a rotary control knob by using a paper-and-pencil test. The subjects were asked to indicate in which direction they would turn the control knob to move a display pointer. Of the 24 control-display arrangements tested, only one yielded a stereotype that was the same for both American and Japanese subjects which indicate reversible stereotype of clockwise movement to increase the pointer value and anti-clockwise movement to decrease it. Courtney's work (Courtney, 1988) examined direction-of-motion stereotypes among the Chinese population where he used a paper-and-pencil test of three-dimensional drawings of display-control devices. From his work, he found that when the control was rotary and arrayed in the horizontal and frontal planes, strong reversible stereotypes were obtained for clockwise-right/anti-clockwise - left. The work also suggested that the clockwise motion were the usual responses requiring an up/down movement of the dot, except in the sagittal plane where subjects preferred the anti-clockwise relation.

Meanwhile in the cooker-control configuration, Hsu and Peng (1993) surveyed 431 participants with three questionnaires (alpha, sign and numerical) of cooker-control displays. Results from this study showed that Linkage III represents the population stereotypes of cooker-control relationship for Chinese participants in the sign and numerical conditions while Linkage II represented the population stereotypes of cooker-control relationship for American participants. Thus, there are some differences in the responses made by these two ethnic groups in this study. Wu (1997) studied population stereotypes with 1180 participants, using questionnaires for alphabetical and numerical layouts. Consistent with Hsu and Peng (1993) the result from this study found that Linkage III was the population stereotype for Chinese. However, Wu (1997) found that Linkage IV (rather than Linkage II) was the stereotype for American participants. In the Hu (1997) paper, an additional study was carried out with 30 male participants who were asked to interact with a wooden model of a four burner stove. The results showed that Linkage V was the predominant preference for Chinese participants and Linkage II for American participants. Frustratingly, this study was not consistent with Hu’s (1997) paper-pencil test (although it did support the Linkage II stereotypes for American users identified by

Hsu and Peng). The Hsu and Peng (1993) and Wu (1997) studies tend to point to Linkage III as a population stereotype for Chinese users and Linkage II for American users when responses are collected through questionnaires, but the results are far from conclusive.

Following from Chapanis and Lindenbaums's (1959) study, Shinar and Actor (1978) surveyed 222 participants by giving a drawing such as in Figure 2.7 (see Chapter 2) with two questions: "Which knob would you turn on each of the four burners? Indicate by writing a letter on each knob." The second question was, "How confident are you that you choose the correct knob? Indicate your confidence by a number from 1 (not confident at all) to 7 (very confident)." This survey demonstrated that there is no particular linkage that can be considered population stereotypes, i.e., 31% of participants chose Linkage II, 28% (Linkage III), 25% (Linkage I) and 15% (Linkage V).

It is not obvious whether the differences between stereotypes in these results arose from differences in perceptions of the two users groups in terms of how they expected to interact with the cooker controls or whether the difference arose from interpretation of the labelling provided in the different conditions. If the latter is true, then employing a simple form of labelling (such as coloured lights as used in Chapter 3) *could* provide a more consistent outcome. This could mean that there would be a more consistent response for each group, or it could mean that there is a consistent response for all participants. If the former is correct, then we might expect to see strong preferences for a specific Linkage for one group and (perhaps) an equally strong preference for a different Linkage for the other group. If the latter is correct, then we might expect to see no differences between groups but a strong preference for one Linkage overall. Table 4.1 illustrates the summary results of the cooker control compatibility from previous studies. These results show there is no consistency in the preferred arrangement among all the studies. This can suggest that different media of testing (e.g. pencil-paper test, computer simulation or physical prototypes) may affect performance in determining cooker-burner linkages.

This chapter is organised as follows. In Section 4.2 we describe the study design and hypothesis and Section 4.3 describes the participants and procedure of the study. Results analysis will be reported in Section 4.4 and discussion of the results will be in Section 4.5. Section 4.6 will conclude the chapter.

Table 4.1 Summary of various tests of the stereotypes for four-burner stoves, comparing paper and pencil test with hardware test for USA and Chinese population.

AUTHORS	POPULATION	TEST TYPE	CODING	MEASURE	BEST ARRANGEMENT
Chapanis and Lindenbaum (1959)	USA	Hardware	-	Reaction Time	ABDC
Shinar and Acton (1978)	USA	Paper/Pencil	Alpha	Stereotypes	ABDC
Ray and Ray (1979)	USA	Hardware	-	Errors	ABDC
Hsu and Peng (1993)	Chinese	Paper/Pencil	Alpha	Stereotypes	ABCD
Hsu and Peng (1993)	Chinese	Paper/Pencil	Symbols	Stereotypes	ABCD
Hsu and Peng (1993)	Chinese	Computer Simulation	-	Reaction Times, Errors	ABCD
Wu (1997)	Chinese	Paper/Pencil	Alpha	Stereotypes	ABCD
Wu (1997)	Chinese	Paper/Pencil	Symbols	Stereotypes	ABCD
Wu (1997)	Chinese	Hardware	-	Reaction Times, Errors	BACD

*The best arrangement cooker and controls refers to the stove layout corresponding to the controls 1, 2, 3 and 4 in Figure 2.9. The ‘Alpha’ coding corresponds to the labelling of the cooker in Figure 2.9. ‘Symbols’ means non-alphabetic labels.

4.2 Design and Hypotheses

As in the previous chapter, two variants of control-burner arrangement were given to participants to respond to: linear and quadrant control-burner arrangement. The questionnaires employed ambient LEDs as follows:

i. Compatible Red LEDs (CR)
ii. Compatible Blue LEDs (CB)
iii. Compatible Red + Green LEDs (CRG)
iv. Incompatible Red + Green LEDs (IRG)
v. Compatible Red + Blue + Green LEDs (CRGB)
vi. Incompatible Red + Blue + Green LEDs (IRGB)

A total of 12 questionnaires were given to participants with six questions relating to linear arrangement and another six for the quadrant arrangement (see Chapter 3). A set of these questionnaires can be seen in Appendix A. Each participant answered 24 different cooker-burner arrangements in linear and quadrant rotary knob arrangements, each with a total of 48 four-burner layouts shown to participants.

For this experiment, the following hypotheses were made.

i. **Hypothesis 1 (H1):** It is expected that Linkage IV will be dominant preference in the compatible red (CR) and compatible blue (CB) based on the finding from previous chapter.
ii. **Hypothesis 2 (H2):** Linkage III will be the dominant preference in the compatible arrangements of linear control arrangement.
iii. **Hypothesis 3 (H3):** Linkage III will be the dominant preference in the all quadrant control arrangement scenarios.
iv. **Hypothesis 4 (H4):** There may be differences in linkage preferences choices made by British and Malaysian participants.

4.3 Participants and Procedures

30 university students were involved in the experiment: 15 participants were Malaysian (9 male, 6 female) and another 15 participants were British (14 male, 1 female). They were aged between 19 and 40 years with an average age of 23 years. Participants had a minimum of one year's experience in the kitchen. These experiences include a participant's familiarity in using cookers in order to perform at least a simple cooking task, such as making an omelette. As all participants lived away from home, they also reported experiencing more than one type of cooker. It is recognised that studies addressing population stereotypes will typically employ several hundred participants and a study with only 30 people can only provide an

approximation of any effect. However, as is discussed below, appropriate statistical adjustment has been made in the analysis of the results.

This experiment measures the possibility of which cooker control linkages were most preferred by Malaysian and British participants in each questionnaire. Thus using frequency of participant responses to each of the linkages, a Chi-Square analysis is run to compare the number of participants who responded to Linkage III with the number of participants responding to other linkages within and between the two groups (Malaysian and British). Due to the small sample sizes, the results will be reported in a Likelihood Ratio followed by the results of effect size and the odds ratio used to summaries a focused comparison in a 2 x 2 contingency table. The odds ratio was calculated as discussed in Chapter 3 (Section 3.3).

To reduce any practice or order effects, the order of presentation of the questionnaires was randomised across participants by using Latin Square. Thus each participant would get a different sequence of questions. Each questionnaire contained the question, ‘Which rotary knob would you use to switch off the lights?” and the participant’s task was to indicate the answer by marking an ‘X’ to the appropriate rotary knob. Participants were only allowed to mark one ‘X’ for each cooker-burner stove and were instructed to complete the questionnaires with their first response, i.e., to not make any alterations to their responses.

4.4 Results

Tables 4.1 (quadrant arrangement) and 4.3 (linear arrangement) summarize the number of participants selecting an option (and the proportion of total responses that these represent) of each possible linkage for Malaysian and British participants in the 12 scenarios of linear and quadrant cooker control arrangements. The results show that there were some similarities and differences in responses between the two cultures. The most common choices are indicated in **bold.** Where there are differences between common choices, the choices are highlighted.

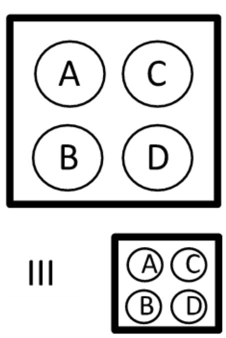
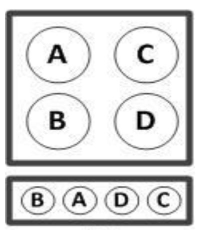


Table 4.2 shows that in the quadrant cooker control arrangements, the majority (more than 3/4) of Malaysian and British participants selected Linkage III in all the scenarios, regardless of whether these had a compatible or incompatible arrangement. In this arrangement, the majority of participants opted for Linkage III, regardless of scenario. This was true for both Malaysian and British participants. Although there was some slight variation in the responses of the Malaysian participants, this does not alter the point that these responses show a majority in all instances.

The Chi-Square analysis (Table 4.3) shows a significant difference in preference for Linkage III compared to other arrangements at the 1% level. Thus, for the quadrant arrangement, a stereotypical response relies on Linkage III, regardless of whether participants are Malaysian or British, or the number of LEDs or whether the arrangement is compatible or incompatible. Thus, hypothesis 3 (H3) is supported. A full result of these analyses is shown in Appendix D. These results show that hypothesis 4 (H4) is not supported in the quadrant cooker arrangements.



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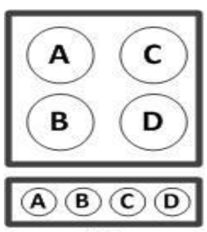
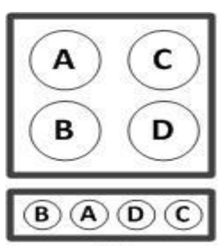


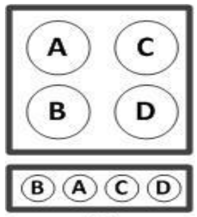
III



IV

The pattern of responses for the linear arrangement is far less consistent. While it was expected that Linkage IV would be the predominant response linkage (as found in Chapter 3) in single LEDs, both Malaysian and British participants responded differently in these scenarios. This is being illustrated in Table 4.4.

The analysis of preference for responses in the linear arrangement begins with two single LED scenarios. In the compatible Red (CR) scenario, Linkage III was chosen by 1/3 of Malaysian participants and 1/3 of British participants. However, the second most-preferred response for each group of participants attracted a similar rate of responses: for Malaysian participants this was Linkage IV and for British participants it was Linkage V (closely followed by Linkage IV).



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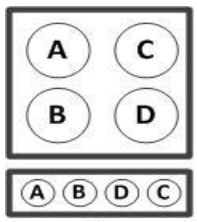
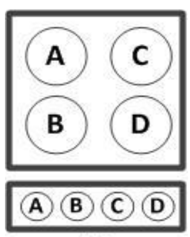


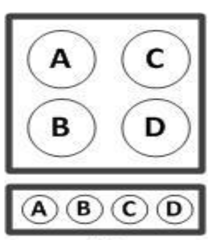
II



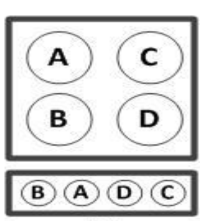
III

In the compatible Blue (CB) scenario, there is even less consistency; Linkages II and IV were similarly preferred by the Malaysian participants and Linkages II, III, IV and V by the British participants. Thus, while Linkage III featured in the most common preferences, it was by no means any more common than others. Thus, Hypothesis H1 is supported only when British and Malaysian participants respond to Linkage IV in the Blue combination, even though Malaysian preferences were split between Linkages III and IV in this combination.

Increasing the number of LEDs from 1 to 2 begins to have an impact on preference. For British participants, Linkage III now becomes the most common linkage preference (in the compatible Red-Green – CRG). While Linkage III is also popular with the Malaysian participants, it is closely followed by Linkage IV. Responses to the incompatible arrangements were varied with Malaysian participants selecting Linkages III and XII and British participants selecting Linkages V and XII.

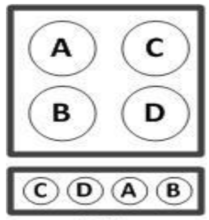


III

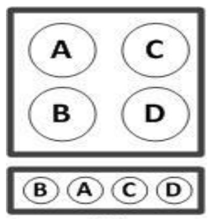


IV

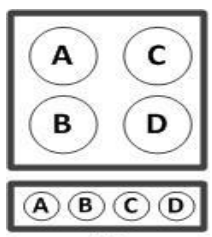
Increasing the number of LEDs from 2 to 3 had an impact of preference for Linkage III for Malaysian participants (with Linkage IV in second place) and for British participants



XII



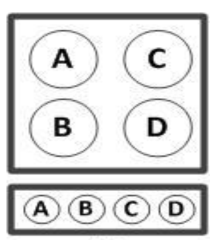
V



III

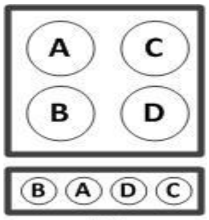
responding to Linkage III (with Linkages V and II in second place). A Chi-Square analysis was conducted to analyse the preference for Linkage III. Likelihood Ratio results showed that Linkage III was not selected significantly more than other linkages in CR [x^2 (1) = 0, p = 1], CB [x^2 = 0.187, p = 0.666], CRG [x^2 (1) = 2.170, p = 0.141], IRG [x^2 (1) = 0.241, p = 0.623], CRGB [x^2 (1) = 0.687, p = 0.407] and IRGB [x^2 (1) = 0, p = 1]. This means that hypothesis 2 (H2) cannot be supported.

A further Chi-Square analysis was conducted to compare the two cultural groups (Malaysian and British) in their selection of Linkage III in preference to other linkages. Table 4.5 shows the Likelihood ratio analysis of linear LEDs arrangement for both Malaysian and British participants. The results of these analyses are shown in Appendix D.

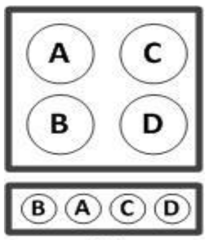


III

As the number of LEDs increases to 3, the preference for Linkage III again fails to become significant. This is interesting because Linkage III had the highest number of responses in the incompatible scenario but participants made a wide range of alternative choices.



IV



V

Meanwhile, preferred linkages choices made by Malaysian and British participants in the linear cooker arrangement were about the same in most scenarios. Both groups made a preference linkages choice to Linkage III in compatible Red (CR), Linkage IV (CB) even though Malaysian participants split the preferences with Linkage III. Both groups agreed Linkage III was the preferred linkage in the compatible Red-Green (CRG) and compatible Red-Green-Blue (CRGB) scenarios as well as in the incompatible Red-Green-Blue (IRGB) scenario. However, Malaysian participants preferred Linkage III in the incompatible Red-Green (IRG) while the British response was to prefer Linkage V.

Table 4.2 Preference linkages responses by Malaysian and British participants in the quadrant cooker arrangement.

		Malaysian Participants						British Participants					
Linkage		**CR**	**CB**	**CRG**	**IRG**	**CRGB**	**IRGB**	**CR**	**CB**	**CRG**	**IRG**	**CRGB**	**IRGB**
II	**ABDC**		**1 (.07)**			**1 (.07)**							
III	**ABCD**	**15 (1.0)**	**13 (.87)**	**14 (.93)**	**13 (.87)**	**12 (.80)**	**12 (.80)**	**15 (1.0)**	**13 (.87)**	**15 (1.0)**	**15 (1.0)**	**14 (.93)**	**14 (.93)**
IV	**BADC**						**1 (.07)**						
V	**BACD**												
VI	**BDAC**												
VII	**ACBD**					**1 (.07)**						**1 (.07)**	
There were no responses to Linkages VIII (ADBC), IX (BDCA) and X (BCAD)													
XI	**CADB**												
XII	**CDAB**												
XIII	**CDBA**												
Others									**1 (.07)**				
Redundancy (R)			**1 (.07)**	**1 (.07)**	**2 (.07)**	**1 (.07)**	**2 (.13)**		**1 (.07)**				**1 (.07)**
	Total:	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**

**Redundancy is the number of participants who chose the rotary knob twice.*
*** Number inside the parentheses is percentages.*

Table 4.3 Chi-Square Analysis of Quadrant Cooker Arrangements

		QUADRANT COOKER CONTROL ARRANGEMENT.											
		LINKAGE III											
		CR		**CB**		**CRG**		**IRG**		**CRGB**		**IRGB**	
		M'sia	***British***	***M'sia***	***British***	***M'sia***	***British***	***M'sia***	***British***	***M'sia***	***British***	***M'sia***	***British***
II	**M'sia**	*		*		*		*		*		*	
	British		*		*		*		*		*		*
IV	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*
V	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*
VI	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*
VII	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*
XI	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*
XII	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*
XIII	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*
O	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*
Redundancy (R)	***M'sia***	*		*		*		*		*		*	
	British		*		*		*		*		*		*

** p < 0.001, ** p < 0.05, n.s = not significant*

Table 4.4 Preference Linkage responses by Malaysian and British participants in the linear arrangements

		Malaysian Participants						British Participants					
Linkage		**CR**	**CB**	**CRG**	**IRG**	**CRGB**	**IRGB**	**CR**	**CB**	**CRG**	**IRG**	**CRGB**	**IRGB**
II	**ABDC**	**2 (.13)**	**1 (.07)**	**1 (.07)**	**2 (.13)**	**2 (.13)**		**2 (.13)**	**3 (.20)**	**2 (.13)**	**2 (.13)**	**3 (.20)**	
III	**ABCD**	**5 (.33)**	**4 (.27)**	**6 (.40)**	**3 (.20)**	**5 (.33)**	**4 (.27)**	**5 (.33)**	**3 (.20)**	**10 (.67)**	**2 (.13)**	**3 (.20)**	**4 (.27)**
IV	**BADC**	**4 (.27)**	**4 (.27)**	**5 (.33)**	**2 (.13)**	**3 (.20)**		**3 (.20)**	**4 (.27)**		**1 (.07)**		
V	**BACD**	**2 (.13)**	**3 (.20)**	**1 (.07)**	**2 (.13)**	**2 (.13)**	**2 (.13)**	**4 (.27)**	**3 (.20)**	**3 (.20)**	**4 (.27)**	**3 (.20)**	**2 (.13)**
VI	**BDAC**												
VII	**ACBD**				**1 (.07)**	**1 (.07)**	**1 (.07)**	**1 (.07)**	**1 (.07)**		**1 (.07)**	**1 (.07)**	**1 (.07)**
No responses were made to Linkages VIII (ADBC), IX (BDCA) and X (BCAD)													
XI	**CADB**	**2 (.13)**	**2 (.13)**	**1 (.07)**	**2 (.13)**	**2 (.13)**	**2 (.13)**				**1 (.07)**		
XII	**CDAB**				**3 (.20)**		**1 (.07)**				**3 (.20)**		
XIII	**CDBA**						**2 (.13)**						**2 (.13)**
Others							**1 (.07)**						**1 (.07)**
Redundancy*			**1 (.07)**	**1 (.07)**		**1 (.07)**	**2 (.13)**					**1 (.07)**	**2 (.13)**
	Total:	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**

*** Number inside the parentheses is percentages.*

**Redundancy is the number of participants who chose the rotary knob twice.*

Table 4.5 Chi-Square Analysis of Linear Cooker Arrangements

		LINEAR COOKER CONTROL ARRANGEMENT											
		LINKAGE III											
		CR		CB		CRG		IRG		CRGB		IRGB	
		M'sia	British	M'sia	British	M'sia	British	M'sia	British	M'sia	British	M'sia	British
II	M'sia	n.s		n.s		**		n.s		n.s			
	British		n.s		n.s		**		n.s		n.s		
IV	M'sia	n.s		n.s		n.s		n.s		n.s			
	British		n.s		n.s				n.s				
V	M'sia	n.s		n.s		**		n.s		n.s		n.s	
	British		n.s		n.s		**				n.s		n.s
VI	M'sia												
	British												
VII	M'sia				n.s			n.s		n.s		n.s	
	British		n.s						n.s		n.s		n.s
XI	M'sia	n.s		n.s		**		n.s		n.s		n.s	
	British								n.s				
XII	M'sia							n.s				n.s	
	British												
XIII	M'sia											n.s	
	British												n.s
O	M'sia											n.s	
	British												n.s
Redundancy	M'sia			n.s		**				n.s		n.s	
	British										n.s		n.s

**p < 0.001, **p < 0.05, n.s = not significant*

4.5 Discussion

This study considered whether there was a difference in preference for Linkage III between Malaysian and British participants. Both groups showed preference for Linkage III only in the 2- LED scenarios. Arrangement and number of LEDs in the cooker controls layout are important factors in deciding the preference for linkages. As the number of LEDs increases in the compatible scenarios, it leads to more variation in response for Malaysian, but not British, participants.

For the single LEDs scenario, a Chi-Square analysis shows that preference for Linkage III is not significant compared to any other linkage. These results suggest that no particular linkage can be considered to be stereotypes in CR and CB for either group. While the results from a small sample need to be treated with caution, this does contradict previous studies. For example, Hsu and Peng (1993) showed Linkage III represents the population stereotype for Chinese and Linkage II for American. One might argue that comparisons of Malaysian with British participants are not equivalent to comparing Chinese with American participants, so any differences between these results and those of Hsu and Peng (1993) could be explained by additional cultural factors. The point to be made in this chapter is that there were no clear and obvious differences between the two groups and neither indicate a strong preference for Linkage III for single LEDs.

When the number of LEDs increases from 1 to 2, Linkage III becomes the preferred linkage for Malaysian participants in the CRG scenario (although only for 2/5 of British participants). However, when the number of LEDs increases in the incompatible arrangement, the number of responses varied. This result is consistent with Experiment 1 (Chapter 3) and previous studies, which suggested that as the stimuli set becomes incompatible with the response set, responses will be varied and confused. Unfortunately, as the number of LEDs increases from 2 to 3, preference for Linkage III declines. In the CRGB scenario, there are no dominant linkages for either group. These results suggest that as the number of LEDs increase, cueing information can become confusing.

i. **Hypothesis 1 (H1):** It is expected that Linkage IV will be dominant preference in the compatible red (CR) and compatible blue (CB) based on the finding from the previous chapter. This hypothesis is not supported.
ii. **Hypothesis 2 (H2):** Linkage III will be the dominant preference in the compatible arrangements of linear control arrangement. This hypothesis is (partially) supported but only in compatible conditions with 2 LEDs or with a single Red LED.
iii. **Hypothesis 3 (H3):** Linkage III will be the dominant preference in the all quadrant control arrangement scenarios. This hypothesis is supported.
iv. **Hypothesis 4 (H4):** There may be differences in linkage preferences choices made by British and Malaysian participants. This hypothesis is not supported. The results suggest that Linkage III is the population stereotype of both Malaysian and British participants when two LEDs are compatible. However, with a small sample size, caution must be

applied as the finding might not be transferable to relevant results of determining the population stereotypes.

4.6 Conclusions

This chapter measures preference cooker control linkages of Malaysian and British users in order to determine stereotypes. A questionnaire consisting of layouts of four cooker controls was given to participants with ambient display as the cueing information. Though the number of participants involved in this study is low (15 participants from each culture), it is still believed that the data and analysis show preliminary results of preference cooker control linkages for future investigations.

The results of this study presented in Section 4.5 showed that Linkage III becomes the preferred linkage for both Malaysian and British users, but *only* when single Red LEDs are compatible with the four burner layouts (but not with the single Blue LEDs) and two LEDs scenarios. However, there is no significant preference as the number of LEDs increases from two to three. The results suggest that population stereotype of a four cooker controls stove for both Malaysian and British is Linkage III but only under very specific conditions.

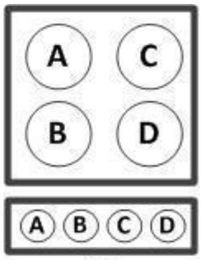
The study differs from previous work because of the presence of additional cues (in the form of blue or green LEDs). Intending to provide support for participants might create a degree of confusion. Alternatively, the additional cues could be ignored in favour of the Red LED (which represented the burner on the stove which was turned on). In this case, participants would only respond to the single cue. However, if this was the case then one would anticipate greater consistency in responses where the Red LED appeared. Considering the two LEDs scenario, it might be proposed that the additional cue provided support to the response to the Red LED – so the redundant information in the second cue was assimilated with the response to the Red LED. When there were two additional cues, then the assimilation became more difficult, leading to confusion. This was particularly apparent when there were contradictions between the red LED and the other two.

One implication of this is that providing people with an opportunity to physically respond to the cues could provide evidence for prioritisation of one cue over the others. In other words, if the red LED *is* the dominant cue and is in a position compatible with the assumed control layout, then one would expect responses to be faster *regardless* of the presence of additional cues. However, if the additional compatible cues speed up performance or incompatible cues slow down performance, then participants would be assumed to be assimilating information from these additional cues. The next chapter will discuss further stimulus-response compatibility in the cooker stove by using a working prototype hardware.

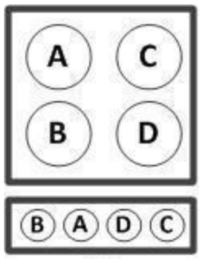
CHAPTER 5
Stimulus –Response Compatibility in an Ambient Stove

Chapters three and four presented studies on stimulus-response (SR) compatibility of cooker controls using the questionnaire approach. Of particular interest is the question of how the potential combination of simple cues (in the form of multiple LEDs) could support interactions. These simple cues represent a form of ambient display.

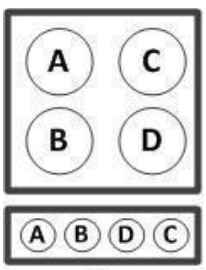
This chapter explores and expands the question of cooker control S-R compatibility by moving from paper-based to a functional prototype of the simple ambient display concept. While findings from Chapters 3 and 4 provide some indication that a simple ambient display *might* affect performance (either in terms of enhancing selections or in terms of creating confusion), this chapter explores the impact on human performance in terms of response time and error rates when ambient cueing is implemented in a functional prototype.



III



IV



II

Several studies have investigated the physical arrangements of cooker controls on the model of four burner stoves. Previous studies showed that reaction times to Linkage III and IV were about the same but slower than Linkage I and II when used as a model of a stove (Chapanis and Lindenbaum, 1959). Meanwhile, 105 errors were made in Linkage III and IV, 6% in Linkage II and no errors in Linkage I. This suggests that contrary to the results from Chapters 3 and 4 (which implied a preference for Linkage III), Linkage II could be preferable.

Ray and Ray (1979) used a cooker control simulator to control 'in line' and 'quadrant' cooker control layouts. The results revealed no errors with the 'in line' arrangement and the most errors in the 'quadrant' cooker control was in Linkage IV (19.2%) arrangement followed with Linkage III(16.3%), Linkage VII (12.2%) and Linkage II (8.6%).

Hsu and Peng (1993) used a computer simulator to test four types of cooker control linkages; II, III V and IV. The task was to turn off the light spot by pressing the 'correct' key control as quickly as possible and if errors were made, participants were required to press another key until the correct one was found. Results showed that Linkage III was the preferred arrangement with response times were 0.63s and 4.33% of errors rates. This is contrary to earlier studies and corresponds with the paper-based studies. However, it is suggested that clicking on the computer screen is more similar to circling an option on the paper-based questionnaires – and so one might expect similar results.

Motivated from previous studies, Wu (1997) measured reaction times and errors by using a wooden four-burner with a dimension of 46cm wide, 61cm long and 15cm high. Coloured perspex discs were used for burners, illuminated by small LEDs. The controls were push buttons – fitted on the front vertical panel for the stove. The circuits were arranged so that one of the burners could be lit automatically by a computer and turned off when the participant pressed the correct control. A timer ran in the computer and served as the measuring instrument. The results of this study showed that for Chinese participants, Linkage V was the preferred arrangement with response times 0.64s and 2% of error rates but Linkage II for American participants with response times 0.69s and 2.5 % of error rates.

This review suggests that there is much confusion and ambiguity in the literature regarding preference for different linkages when people interact with physical models. This might be due to the nature of the interaction or to the additional information that is presented to the users, or it might be due to expectations and experience of people from different cultures. In this chapter, a study is presented in which users from two cultures interact with the working prototype of the ambient stove.

This chapter is organised into five sections; section 5.2 describes the design and hypothesis of the study. Section 5.3 describing the participants and procedure of the study followed with result analysis reported in section 5.4. Section 5.5 discusses the results and section 5.6 concludes the chapter.

5.1 Design and Hypotheses

Motivated by the previous studies, a model of a four cooker control stove was designed and built. The apparatus used in this experiment is an aluminium model of a four-burner stove named *Ambient Stove* as shown in Figure 5.1.

The model is small enough to sit on a desk and measures 20cm width by 20cm length by 35cm height. It consists of an aluminium frame on which push button controls are located on the back for the experimenter to set the experimental layout, LEDs for cueing, and rotary knobs for participant responses. Three colours of LEDs were used, the red and blue LEDs were aligned as a quadrant and fitted on the hob and in the hood, and the green LEDs were in the front of the hood and aligned with rotary controls. Each LED was 5mm in diameter and was switched on by the experimenter using the push button behind the stove panel. A simple electronic circuit in Figure 5.2 was designed so that when the experimenter presses the ‘push button’, LED(s) will switch ON and a relay will trigger the stopwatch to start. The stopwatches were connected with the circuit and served as the measuring instrument to record the reaction times. The LED(s) and stopwatches switch OFF when participants choose the correct rotary knob. The circuits are installed inside the ‘stove’ and are powered by 12v power supply. As the stove was to be tested (and demonstrated) in different locations a self-contained unit was designed that did not require interfacing to a computer.

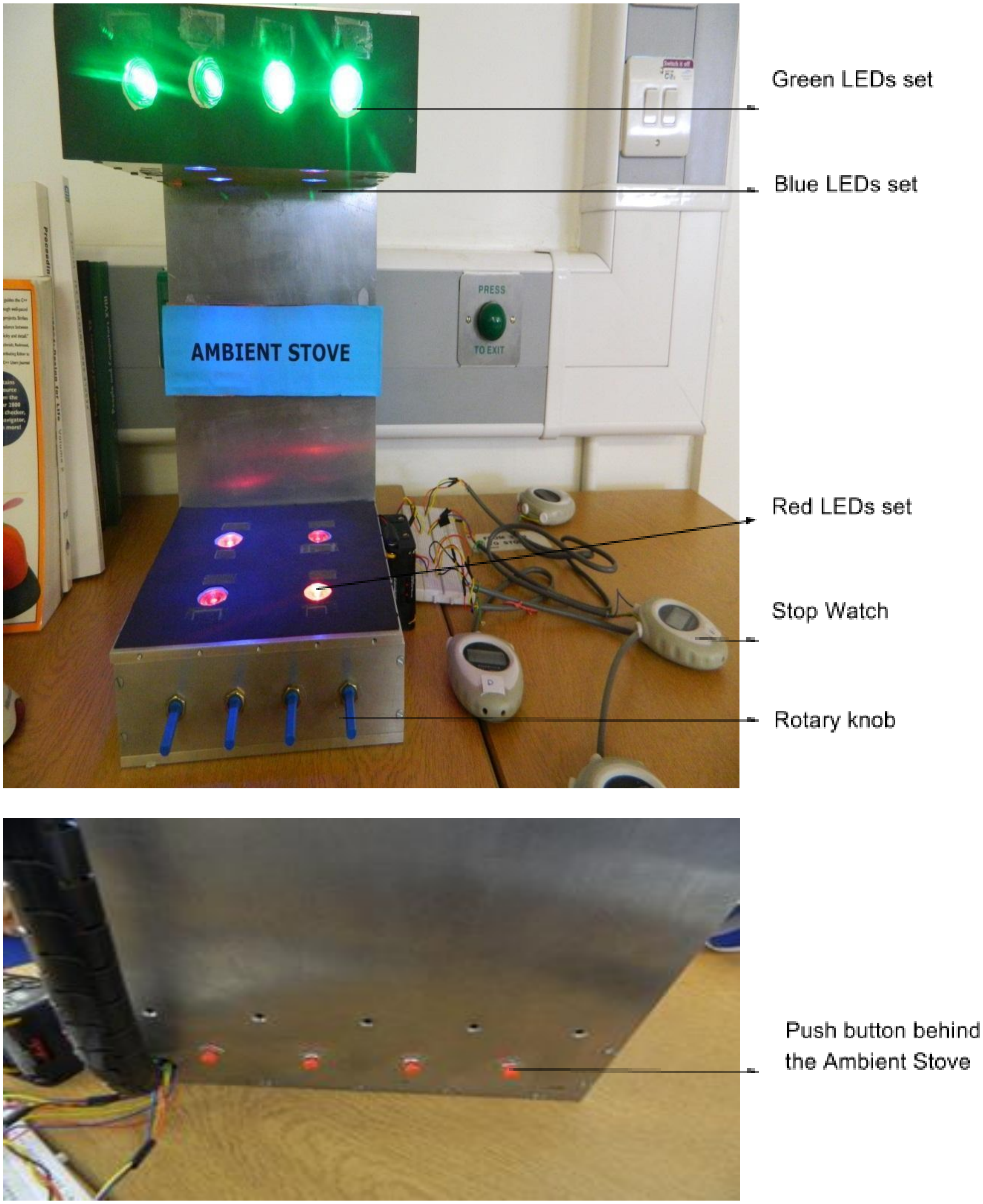


Figure 5.1 Physical Model of Ambient Stove

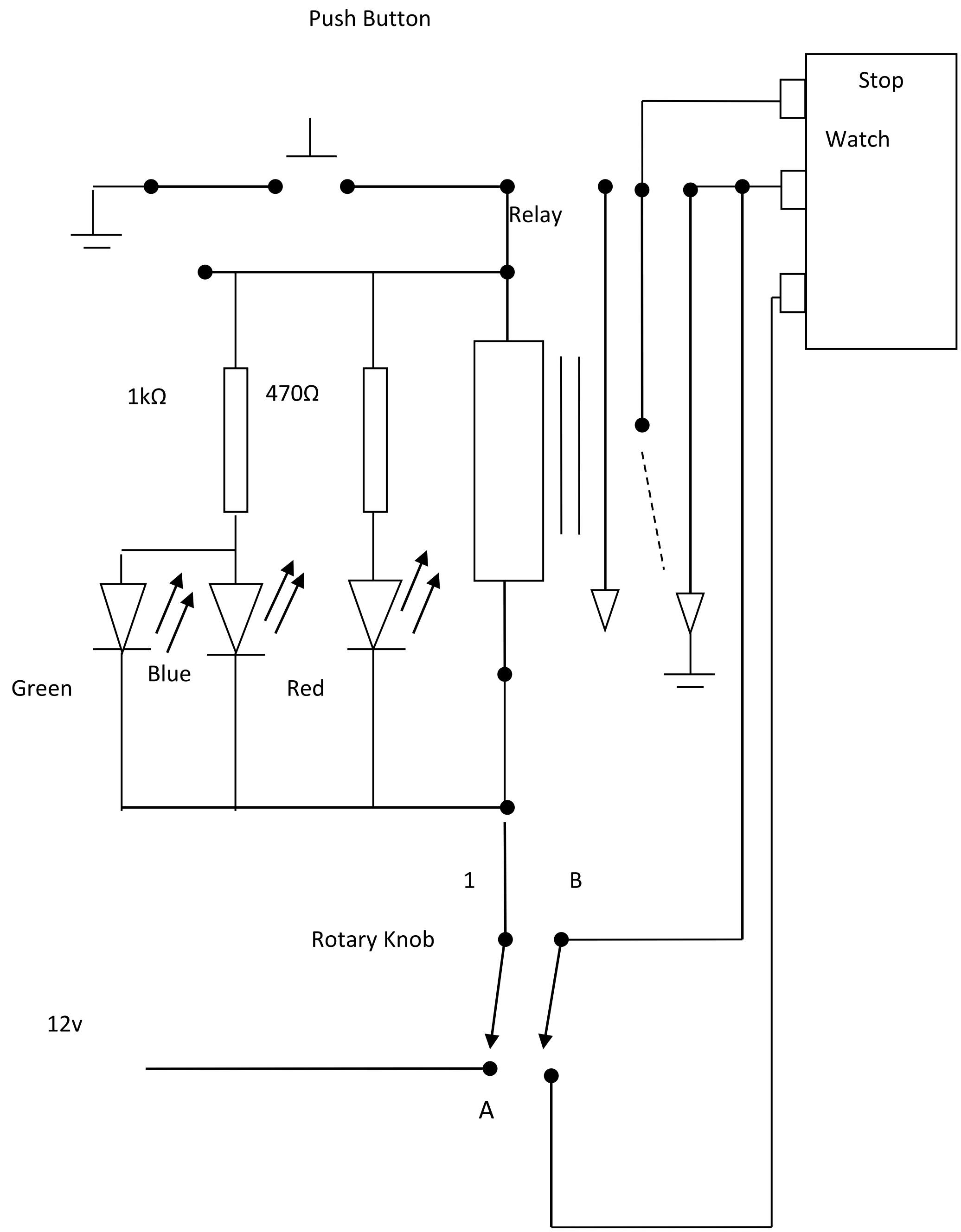


Figure 5.2 A schematic diagram of electric circuits in Ambient Stove

Six (6) combinations of ambient display were tested in randomised orders. Each combination had two (2) types of arrangement; incompatible and compatible. Each combination was tested four (4) times with different positions of LEDs. Therefore each participant was tested with 12 different layouts of control-burner arrangement, which resulted in 48 (6 x 2 x 4) trials. The combinations were as follows:

i. Compatible and incompatible Red LEDs (CR and IR)
ii. Compatible and incompatible Blue LEDs (CB and IB)
iii. Compatible and incompatible Green LEDs (CG and IG)
iv. Compatible and incompatible Red-Green (CRG and IRG)
v. Compatible and incompatible Red-Blue (CRB and IRB)
vi. Compatible and incompatible Red-Green-Blue (CRGB and IRGB)

The primary objective of this study is to explore the response to control burner linkages using ambient cueing by using a model stove between two different cultures; Malaysian and British. It is expected that in this study:

- **Hypothesis 1 (H1):** Fewer attempts are made when there is spatial compatibility between the LEDs and rotary set. This can be assumed based on the previous study in Chapters 3 and 4 in which linkage mapping to this combination is consistent.
- **Hypothesis 2 (H2):** Fewer attempts are made as the number of LEDs increase in the compatible arrangement than in the single LEDs. This can be assumed that as the number of LEDs increases in the compatible arrangement, it does help users make a response decision as Chapters 3 and 4 showed response to Linkage III is higher as the number of LEDs increases.
- **Hypothesis 3 (H3):** Response times are faster when there is spatial compatibility between the LEDs and rotary set. Findings in chapters 3 and 4 show there is consistent

response towards Linkage III when there is compatibility; therefore, it is expected that response times are consistent and faster.

- **Hypothesis 4 (H4):** Response times are faster as the number of LEDs increases in the compatible arrangement than in the single LEDs. Findings in chapter 3 show that as the number of LEDs increases, response toward Linkage III also increases compared to 2 LEDs. This suggests that response times may be faster too.
- **Hypothesis 5 (H5):** A higher number of attempts and slower response times are made in the incompatible arrangement than the compatible. This is suggested from the findings in previous chapters that response towards linkage mapping is varied and inconsistent.

5.2 Participants and Procedure

Thirty two (32) students studying at the University of Birmingham were recruited for this study. Sixteen (16) of the participants were Malaysian and another 16 were British. Malaysian participants were aged between 21 to 40 years old, with an average aged of 22 years old. Thirteen (13) participants were female and three (3) were male. Meanwhile, British participants were aged between 18 to 40 years old, with an average aged of 20 years old. Fourteen (14) participants were male and two (2) were female. The participants were from different backgrounds and had an average of 2.5 years of experience in the kitchen environment. There was an interval of four weeks between tests and it was felt that this was sufficient for learning or retention effects to be minimal. (Karpicke and Roediger, 2010) (Roediger and Karpicke, 2006)

Each participant was given a standard instruction at the beginning of the experiment. This explained to each participant how the ambient stove will be used and tested. The instructions emphasised that (1) the participant should put their hand at the resting position before and after the test, (2) only use their dominant hand (3) only turn the rotary knob clockwise to switch off the LED(s), (4) if the LED does not turn off – the participant needs to turn another rotary knob until the LED does turn off. When both participant and experimenter were ready, the experimenter would give a ready signal, and shortly thereafter turn ON one of the LED(s) on the panel. To reduce the expectations, the orders of presentations of combinations were randomised across and within participants.

If the participant turned the correct rotary knob, the LED went off and the stopwatch stopped. If the participant turned an incorrect rotary knob, the LED stayed on and the stopwatch continued running. The instruction emphasized that if participants made an error, they needed to correct it immediately by choosing another rotary knob until the correct one was found. Participants were tested individually and each test session lasted approximately one hour. The experimenter recorded (1) the time of the first response, (2) the time until the correct response if the first response was incorrect and (3) the number of attempts before getting the right response.

Figure 5.3 Participant responds to single LEDs from L to R: Red, Blue and Green LED.

Figure 5.4 Participant responds to 2 or 3 combination of LEDs, from L to R: Red-Green, Red-Blue and Red-Green-Blue

5.3 Results

For the purpose of this experiment and other experimental studies in Chapter 6 and 7, two-tailed tests will be conducted. Each study has several hypotheses that are directional (which requires one-tailed test) and some that are not (which required two tailed tests). For example, suppose the study has a hypothesis that Group A will be better than Group B (A > B). This hypothesis claims that a direction of effect and one-tailed test will be used. Now suppose the hypotheses indicate there will be a difference between Group A and Group B but without specifying which direction this difference will be. In this case a two-tailed test will be used. In some tests such as T-Test, the *p*-value was adjusted by dividing the value by 2 to meet the one-tailed test condition, as SPSS does not provide one-tailed test results.

In this study, a mixed Analysis of Variance (ANOVA) test is used. ANOVA is a statistical model used to analyse the differences between three or more means (groups or variable) to avoid Type I error. Therefore, a series of three-way ANOVA was conducted on the data. Three-way ANOVA was used to measure two independent variables: c***ompatibility*** (compatible and incompatible), and ***conditions*** (Red, Blue, Green, Red-Green, Red-Blue, and Red-Green-Blue). These two variables completely cross-over producing twelve (12) experimental conditions between the dependent variable of ***nationality*** (Malaysian and British).

Results of Mauchly's sphericity test for each of the three effects in the experiment (two main effects and one interaction). The significant values of these tests indicate that the main effects and interaction; (Compatibility, Combination and Condition * Combination) have violated this assumption and so the F-value was corrected to the Greenhouse-Geisser effect. Therefore, three-way ANOVA analysis showed there was no significant effect of nationality, indicating that the number of attempts between Malaysian and British participants was not significantly different [F (1, 30) = 0.476, p = 0.495]. The same results also showed there were no significant effect of nationality in initial response times [F (1, 30) = 0.558, p = 0.461] and correct response times [F (1, 30) = 1.235, p = 0.275].

As there was no effect of nationality, subsequent analysis was performed on the pooled data set, i.e., all participant responses were collected together and the results were subjected to two-way (compatibility x condition) ANOVA.

5.3.1 Number of Attempts

Number of attempts was the number of times participants tried to turn the rotary knob until the correct knob was selected. If the first attempt was correct, the attempt was counted as '1 attempt'. The experimenter counted how many times the participant turned the rotary knobs until the correct LED was turned off in each combination.

Two-way ANOVA was used to measure two independent variables ***compatibility*** *(*compatible and incompatible) *and* ***conditions*** *(*Red, Blue, Green, Red-Green, Red-Blue, Red-Green-Blue). These two independent cross over with dependent variables; ***number of attempts*** with thirty-two (32) different participants were used in each condition.

Results from this two-way ANOVA showed that there was significant difference on the test of homogeneity of variance (see Table 5.1). For the number of attempts, the variance was significantly different between the compatible and incompatible, $F(1,382) = 193.31$, $p < 0.01$.

Table 5.1 Test of Homogeneity of Variance

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Responds	Based on Mean	193.308	1	382	.000
	Based on Median	164.733	1	382	.000
	Based on Median and with adjusted df	164.733	1	371.691	.000
	Based on trimmed mean	194.178	1	382	.000

There was significant main effect of the compatibility on the number of attempts, $F(1, 372) = 641.67$, $p < 0.001$, $\omega = 0.50$ as shown in Figure 5.5. Results also showed there was significant main effect of condition on number of attempts $F(5, 372) = 45.11$, $p < 0.001$, $\omega = 0.17$.

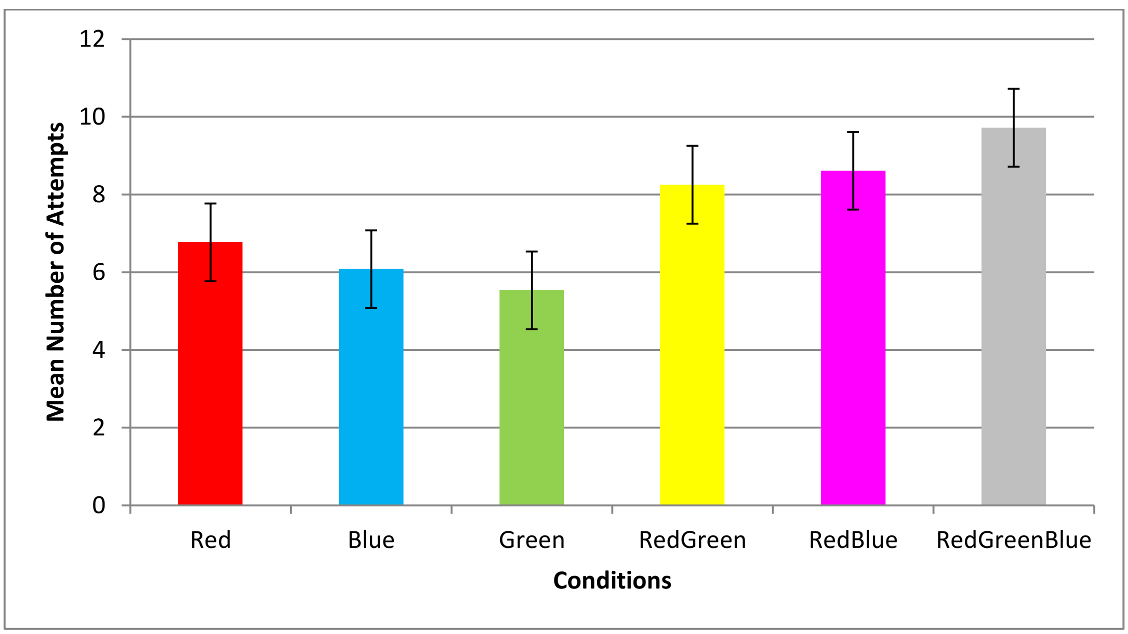


Figure 5.5 Number of attempts across all the conditions in the *Ambient Stove*

There was a significant interaction effect between the compatibility of LEDs' arrangement and the conditions of LEDs, on the number of attempts performed $F(5, 372) = 190.15$, $p < 0.001$, $\omega = 0.016$. This indicates that conditions of LEDs were affected differently by the compatibility arrangement of LEDs as shown in Figure 5.6.

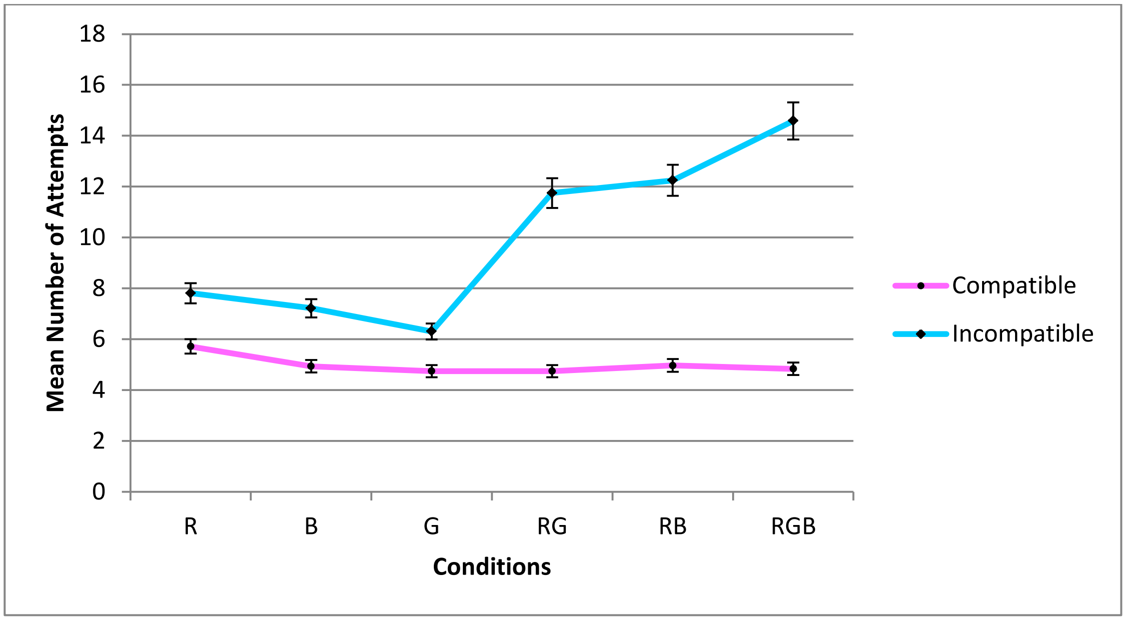


Figure 5.6 Number of attempts in different conditions of LEDs and two different compatibility LEDs arrangement.

The LSD and Bonferroni *post hoc* test revealed that the number of attempts was significantly different in all conditions (*ps* < 0.001) except between Blue to Green condition and Red-blue and Red-Green condition. These results are shown in Table 5.2. Detailed results of these contrasts are shown in Appendix E.

Table 5.2 Contrasting numbers of attempts between the conditions.

	Conditions					
	Red	Blue	Green	Red-Green	Red-Blue	Red-Green-Blue
Red		$p < 0.045$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
Blue	$p < 0.045$		*n.s*	$p < 0.001$	$p < 0.001$	$p < 0.001$
Green	$p < 0.001$	*n.s*		$p < 0.001$	$p < 0.001$	$p < 0.001$
Red-Green	$p < 0.001$	$p < 0.001$	$p < 0.001$		*n.s*	$p < 0.001$
Red-Blue	$p < 0.001$	$p < 0.001$	$p < 0.001$	*n.s*		$p = 0.001$
Red-Green-Blue	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.001$	

n.s = not significant

As the number of LEDs increased, there were significant differences of the number of attempts in Red-Green (RG), Red-Blue (RB) and Red-Green-Blue (RGB) combination both in the compatible and incompatible combinations. These results were significant and suggest as the number of LEDs increase, the number of attempts were higher in the incompatible combinations but lower in the compatible combinations.

On average, participants made fewer attempts in the compatible arrangements than the incompatible arrangement. A pairwise t-test was conducted between compatible and incompatible arrangement for each combination and the results showed that these differences were significant for all combinations as shown in Table 5.3 and illustrated in Figure 5.7. As SPSS provides only the two-tailed significance value, the sig(2-tailed) were divided by 2 to get the one-tailed significance.

Table 5.3 T-Test number of attempts between compatible and incompatible conditions.

		T-TEST					
		COMPATIBLE					
		Red LED	Blue LED	Green LED	Red-Green LED	Red-Blue LED	Red-Green-Blue LED
INCOMPATIBLE	Red LED	p < 0.001					
	Blue LED		p < 0.001				
	Green LED			p < 0.001			
	Red-Green LED				p < 0.001		
	Red-Blue LED					p < 0.001	
	Red-Green-Blue LED						p < 0.001

n.s = not significant

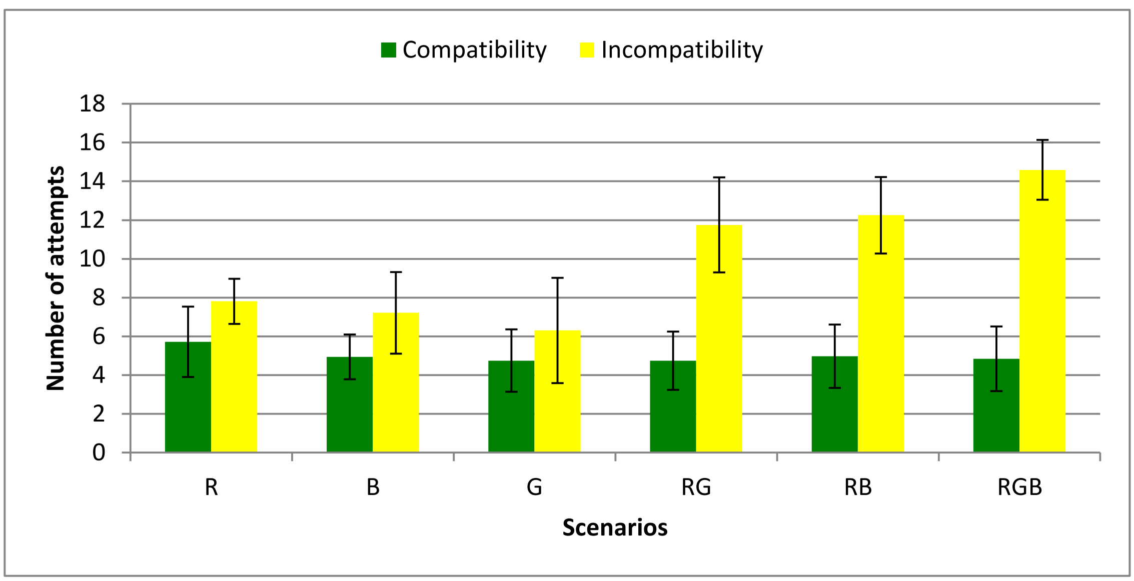


Figure 5.7 Average numbers of attempts between compatible and incompatible combination.

While one might expect the ‘red’ combination to play a dominant role in the task (as this was used to represent the burners on the hob), the design emphasized the spatial alignment between green LEDs and controls. A repeated t-test was conducted for single LEDs both in the compatible and incompatible arrangements. These results are shown in Table 5. 4.

Table 5.4 <u>T-Test results of compatible and incompatible single LEDs.</u>

	T-TEST FOR SINGLE LEDS (COMPATIBLE)		
	Red LED	Blue LED	Green LED
Red LED		$p < 0.005$	$p < 0.005$
Blue LED	$p < 0.005$		n.s
Green LED	$p < 0.005$	n.s	

	T-TEST FOR SINGLE LEDS (COMPATIBLE)		
	Red LED	Blue LED	Green LED
Red LED		$p < 0.005$	$p < 0.005$
Blue LED	$p < 0.005$		n.s
Green LED	$p < 0.005$	n.s	

n.s = not significant

From the table, there was significance between Red and Blue, and Red and Green LEDs, but no difference between Green and Blue LEDs in the compatible arrangements. Meanwhile, in the incompatible arrangement, there were significant differences between Red and Green but there were no significant differences between Red and Blue and Green and Blue. Figure 5.8

and 5.10 illustrate the results on the number of attempts of single lights in the compatible and incompatible arrangement.

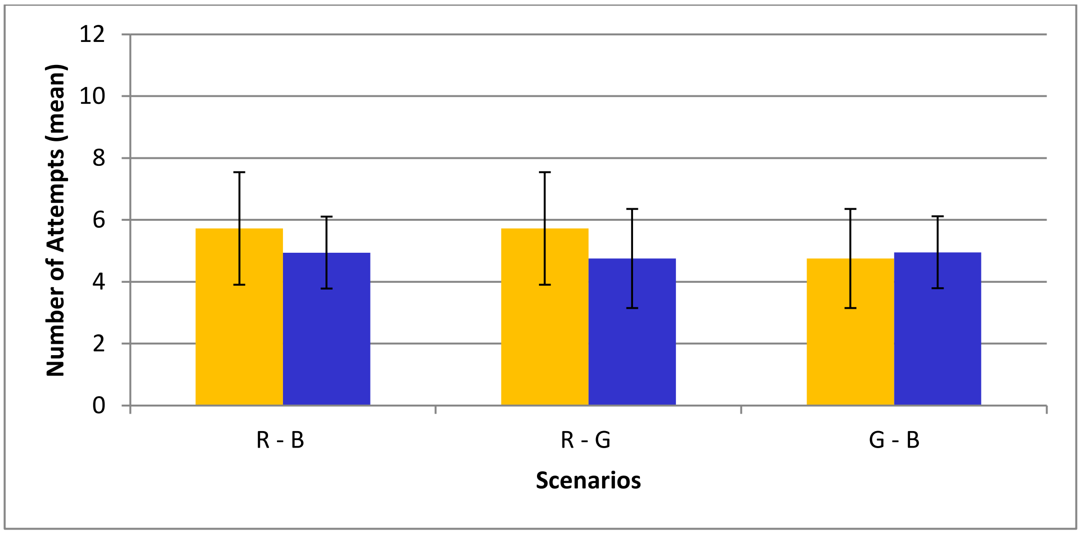


Figure 5.8 Number of attempts between single LEDs in the compatible combinations

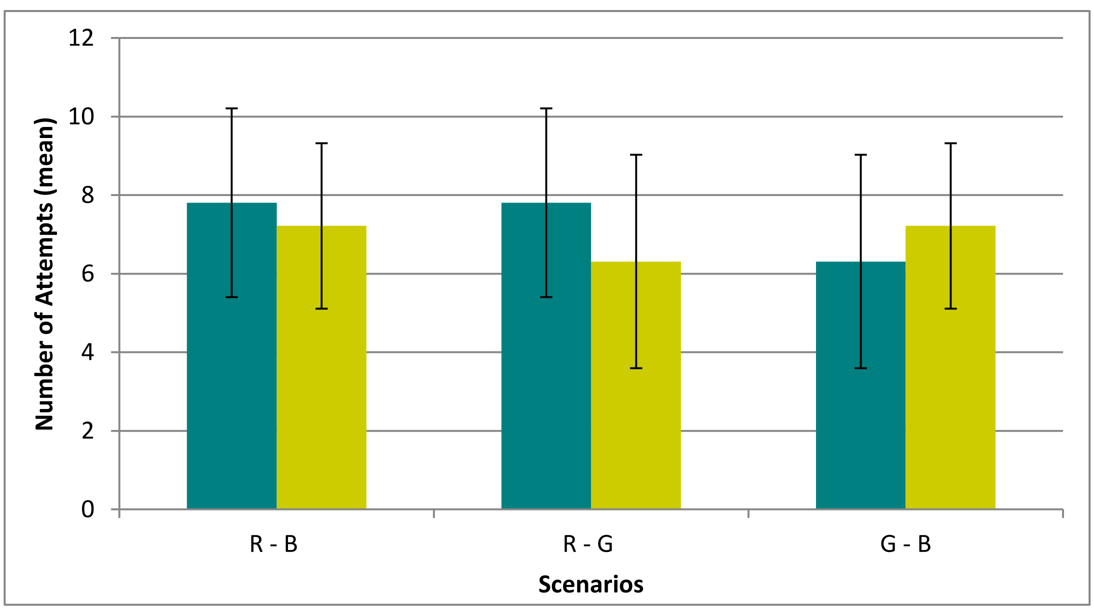


Figure 5.9 Number of attempts between single LEDs in the incompatible combinations.

While Figure 5.9 shows generally a consistent number of attempts across all the compatible but an increase in the number of attempts with an increased number of LEDs in the incompatible conditions. This suggests a further analysis to compare number of LEDs (1, 2 or 3). A repeated measures t-test was conducted in the compatible arrangement to explore the impact of number of LEDs on responses as shown in Table 5.5.

Table 5.5 T-Test results as number of LEDs increases in the compatible combination.

	T-TEST WHEN LEDS INCREASE (COMPATIBLE)		
	Red-Green LED	Red-Blue LED	Red-Green-Blue LED
Red LED	$p < 0.005$	n.s	$p < 0.005$
Blue LED	-	n.s	n.s
Green LED	n.s	-	n.s
Red-Green LED		-	n.s
Red-Blue LED	-		n.s

n.s = not significant

The results in Table 5.5 showed a significant effect of increasing from 1 to more LEDs for the Red LED, i.e. Red to Red-Green (RG) combination, and from Red to Red-Blue-Green (RGB) combination but there was no difference for other pairs of colour LEDs; i.e. Red to Red-Blue, Blue to Red-Blue, Blue to Red-Green-Blue, Green to Red-Green and Green to Red Green Blue combinations. As the number of LEDs increases from 2 to 3, there were no significant differences, i.e. Red-Green to Red-Green-Blue and Red-Blue to Red-Green-Blue. These results are illustrated in Figure 5.10.

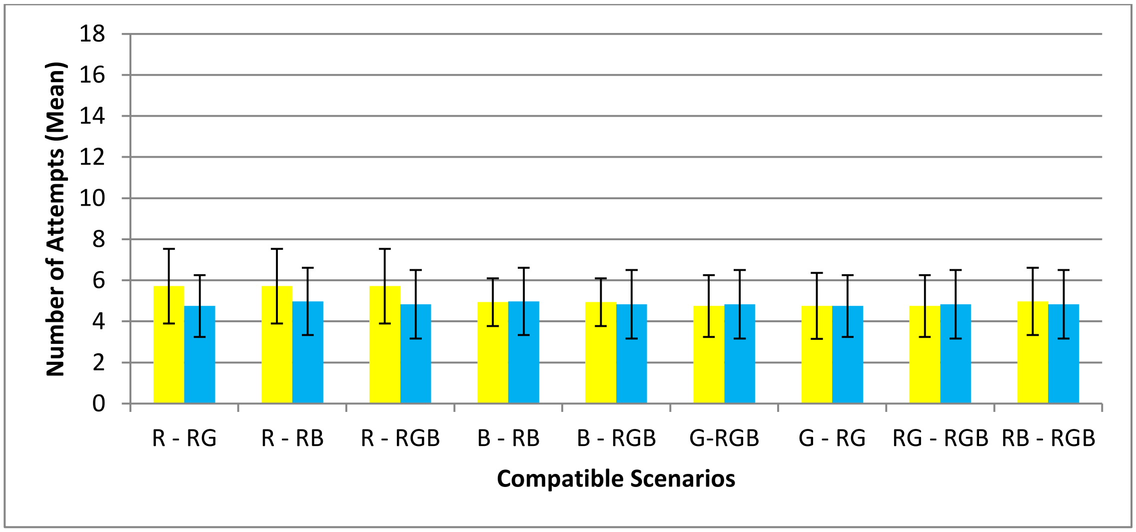


Figure 5.10 Number of attempts as number of LED increase in the compatible condition

A repeated measures t-test was then conducted for incompatible arrangement. Table 5.6 shows the results of this test.

Table 5.6 T-test results as number of LEDs increases in the incompatible condition

	T-TEST WHEN LEDS INCREASE (INCOMPATIBLE)		
	Red-Green LED	Red-Blue LED	Red-Green-Blue LED
Red LED	p < 0.001	p < 0.001	p < 0.001
Blue LED	-	p < 0.001	p < 0.001
Green LED	p < 0.001	-	p < 0.001
Red-Green LED		-	p < 0.001
Red-Blue LED	-		p < 0.001

n.s = not significant

The result show significant differences both in the number of LEDs increasing from 1 to 2 LEDs and from 2 to 3 LEDs, i.e., from Red (R) to Red-Green (RG); from Red (R) to Red-Blue (RB); from Red (R) to Red-Green-Blue (RGB); from Blue to Red-Blue (RB); from Blue (B) to Red-Green-Blue (RGB); from Green to Red-Green (RG); from Green to Red-Green-Blue (RGB); from Red-Green (RG) to Red-green-Blue (RGB) and from Red-Blue (RB) to Red-Green-Blue (RGB). Figure 5.11 illustrates the T-test results of incompatible arrangements.

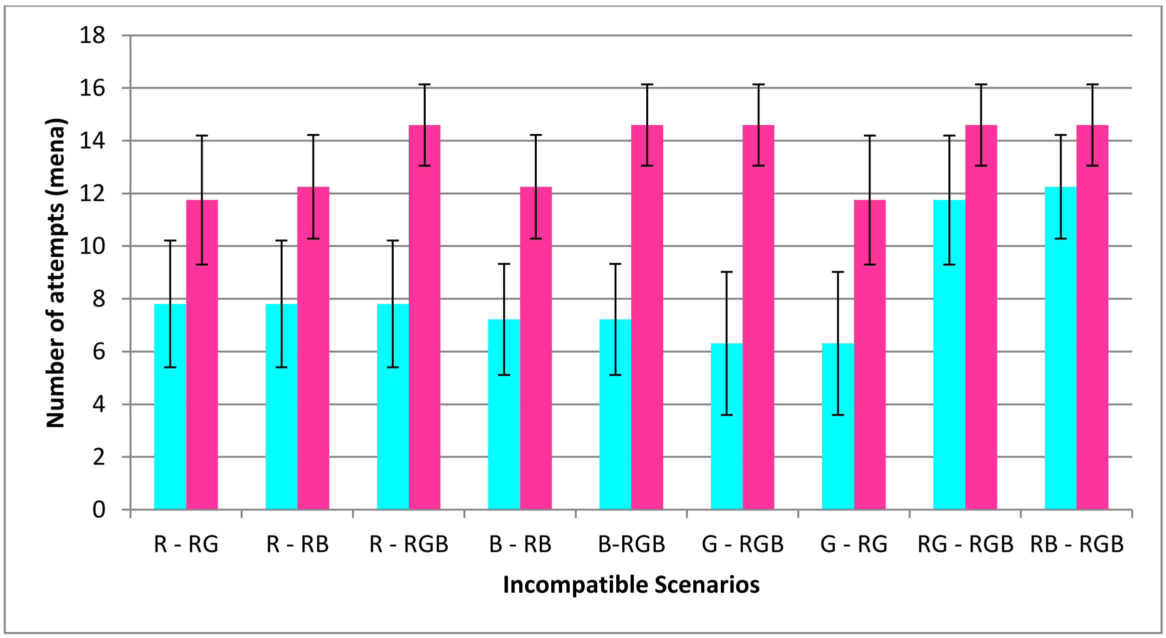


Figure 5.11 Number of attempts as number of LED increase in the incompatible combination

5.3.1.1 Summary Number of Attempts

Results of the number of attempts have shown that when there is spatial compatibility between the LEDs and controller, the number of attempts is lower compared to incompatible combination. As the number of LEDs increases, attempts are lower compared to single LEDs if the compatible arrangements are met. If the number of LEDs increases, in the incompatible arrangements numbers of attempts are higher than any other combinations. Meanwhile, as expected, as green LEDs are in line with the rotary knob, numbers of attempts are lower compared to Red and Blue LEDs. This suggests that spatial compatibility does improve human performance by causing fewer errors and providig faster access to the digital environments.

5.3.2 Response Times

Two types of response time were measured in this experiment: the first one was the initial (the first rotary knob turned) response times (irrespective of whether this was correct or not) and the second was the time to produce a correct response. The stop watch connected to the *Ambient Stove* measured the times in the format of m:s:ms but the analysis and results of this measurement will be reported in the format of second (s).

5.3.2.1 Initial Response Times

Initial times were the first response times of the first rotary knob chosen, regardless of whether it was the correct rotary knob or not.

Two-way ANOVA was used to measure two independent variables: ***compatibility*** (compatible and incompatible) and ***conditions*** (red, blue, green, redGreen, redBlue and redGreenbBlue). These two independent variables cross over with dependent variables; ***initial response times*** with thirty-two (32) different participants were used in each condition.

Results from this two-way ANOVA showed that there was significance on the test of homogeneity of variance (see Table 5.7). For the number of attempts, the variance was significantly different between the compatible and incompatible, $F(5, 378) = 5.460$, $p < 0.01$.

Table 5.7 Test of Homogeneity of Variance

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Initial_Times	Based on Mean	5.460	5	378	.000
	Based on Median	3.589	5	378	.003
	Based on Median and with adjusted df	3.589	5	260.245	.004
	Based on trimmed mean	4.408	5	378	.001

The two-way ANOVA also showed there was significance in the main effect of the compatibility of LEDs arrangement on the initial response times, $F(1, 372) = 38.92$, $p < 0.001$ $\omega = 0.18$. There was a significant main effect of conditions of LEDs on the initial response times $F(5, 372) = 84.29$, $p = 0.01$ $\omega^2 = 0.02$ as clearly shown in Figure 5.12.

However, the results showed that there was a non-significant interaction effect between the compatibility of LEDs and the conditions of LED, on the initial response times, $F(5, 372) = 56.69$, $p > 0.05$, $\omega^2 = 0.01$. This indicates that compatibility of LEDs is not affected differently by conditions of LED on initial response times. Initial response times were almost the same throughout all the conditions both in the compatible and incompatible LEDs' arrangement and showed it was not affected by compatibility (see Figure 5.13)

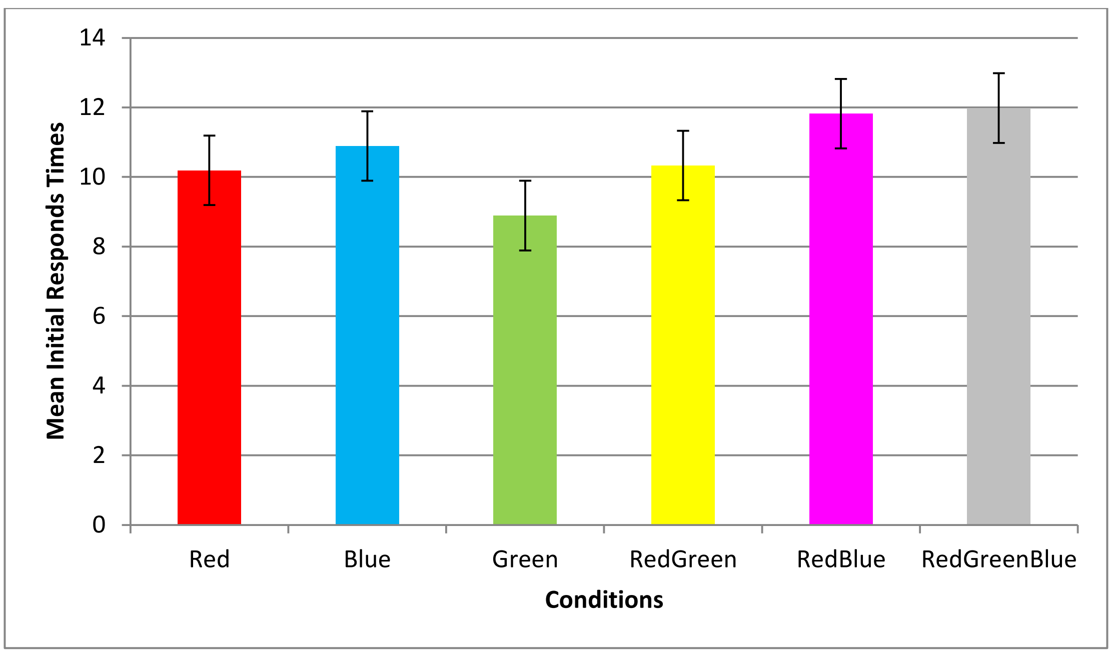


Figure 5.12 Initial Response Times between the conditions.

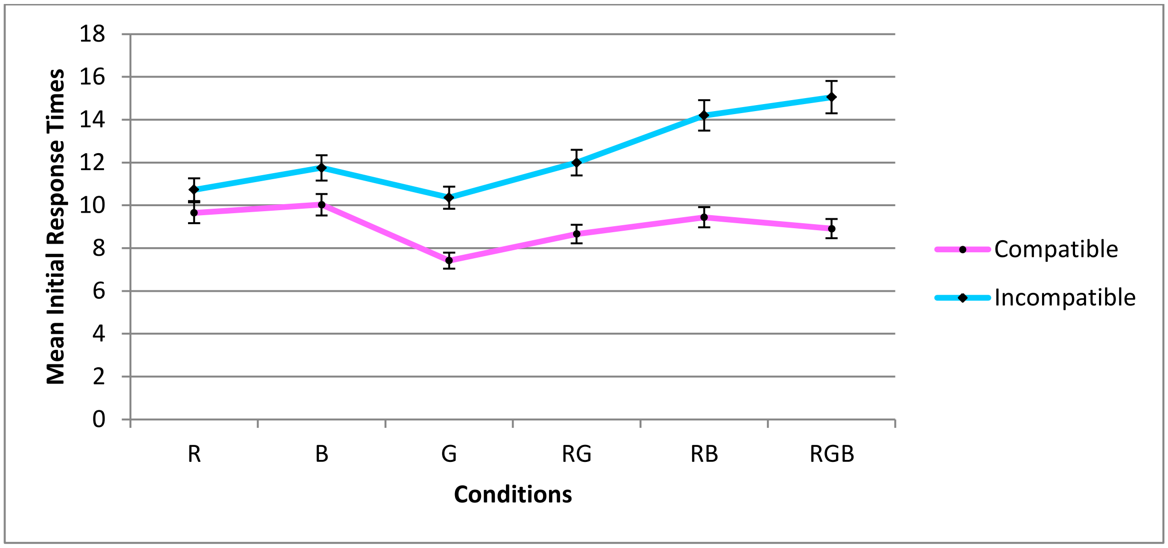


Figure 5.13 Initial response times across compatibility and combinations interactions.

The LSD and Bonferroni *post hoc* test revealed that initial response times were significantly faster in the green condition compare to the blue condition (p = 0.031) and initial response times were significantly slower both in Red-Blue (p = 0.002) and Red-Green-Blue (p < 0.001) condition compared to the Green condition. Table 5.8 illustrates the post hoc test.

Table 5.8 Contrasting the initial response times between conditions.

	Conditions					
	Red	Blue	Green	Red-Green	Red-Blue	Red-Green-Blue
Red		n.s	n.s	n.s	n.s	n.s
Blue	n.s		p = 0.031	n.s	n.s	n.s
Green	n.s	p = 0.031		n.s	p = 0.002	p < 0.001
Red-Green	n.s	n.s	n.s		*n.s*	n.s
Red-Blue	n.s	n.s	p = 0.002	*n.s*		n.s
Red-Green-Blue	n.s	n.s	p < 0.001	n.s	n.s	

n.s = not significant

The first contrast compared an incompatible arrangement of LEDs to a compatible arrangement of Blue (B) to Red (R) LED combinations. This was not significant, although initial response times were slightly faster in the Blue (B) combination when the arrangement of LEDs was compatible compared with when arrangements were incompatible.

The second contrast compared incompatible with compatible arrangements when the combination of LEDs was Green (G) compared with Red (R) combination. This was significant and tells us that as the arrangement of Green (G) LEDs was parallel with the rotary knob, and responses were faster with compatible compared with incompatible arrangements.

The third contrast was comparing incompatible with compatible arrangements when the combination of LEDs was Red-Green (RG) compared to when the combination was Red (R). This indicates that as LEDs were in the Red (R) position and changed to Red-Green (RG) LEDs, the initial response times were faster in the compatible arrangement but slower in the incompatible arrangement. This was significant.

The fourth contrast compared Red-Blue (RB) LED position to Red (R) LED combination in incompatible to compatible arrangements. This was significant and this indicates to us that as the number of LEDs change from Red (R) to Red-Blue (RB), initial response times in the incompatible arrangement were slower than in the compatible arrangements.

The last contrast compared Red-Green-Blue (RGB) LED to Red (R) LED combination with incompatible to compatible arrangements. This comparison was significant and tells us that as the number of LEDs increases from Red to Red-Green-Blue (RGB), initial response times were slower in the incompatible arrangements than in the compatible arrangement. The results of these comparisons are shown in Appendix E and illustrated in Figure 5.14.

A paired T-test between compatible and incompatible conditions was conducted for initial response times. These tests showed no difference for the single Red (R) and Blue (B) LED in compatible or incompatible conditions. However, there were significant differences between compatible and incompatible conditions for all other combinations; these results are shown in Table 5.9 and illustrated in Figure 5.14.

Table 5.9 T-Test initial response times between compatible and incompatible combinations.

		T-TEST					
		COMPATIBLE					
		Red LED	Blue LED	Green LED	Red-Green LED	Red-Blue LED	Red-Green-Blue LED
INCOMPATIBLE	Red LED	p < 0.001					
	Blue LED		p < 0.001				
	Green LED			p < 0.001			
	Red-Green LED				p < 0.001		
	Red-Blue LED					p < 0.001	
	Red-Green-Blue LED						p < 0.001

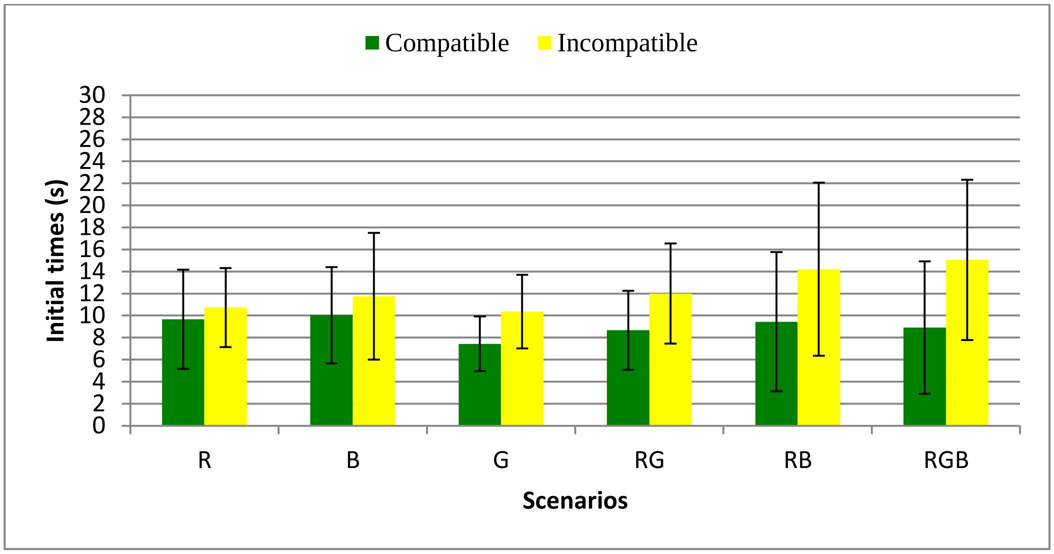


Figure 5.14 Initial response times across combinations between compatible and incompatible combinations.

A series of repeated measure T-Tests were conducted for the initial response times as the number of LEDs increased both in the compatible and incompatible arrangement. In the compatible condition, the results showed there were no significant differences in all the combinations except when the LED was in the Green (G) condition (one LED) and changed to the Red-Green condition (two LEDs). As the number of LEDs increased from 2 to 3 LEDs, there was no significance found. These results are shown in Table 5.10 and illustrated in Figure 5.15.

Table 5.10 T-Test initial response times as the number of LEDs increases from 1 to 2 to 3 LEDs in the compatible arrangements.

	Red-Green LED	Red-Blue LED	Red-Green-Blue LED
Red LED	n.s	n.s	n.s
Blue LED	-	n.s	n.s
Green LED	$p < 0.05$	-	n.s
Red-Green LED		-	n.s
Red-Blue LED	-		n.s

n.s = not significant

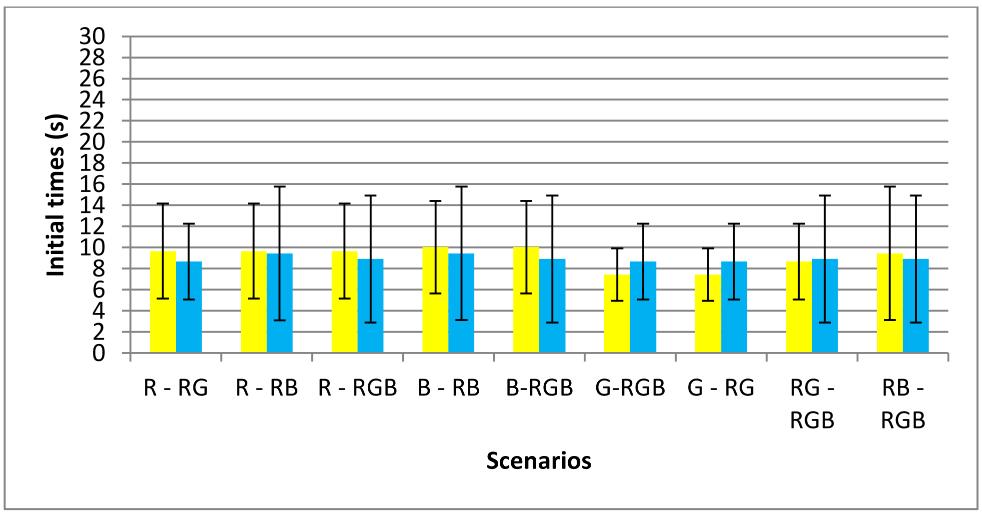


Figure 5.15 T-Test results of initial response times as the number of LEDs increases in the compatible arrangements.

Meanwhile, in the incompatible arrangement, a repeated measures t-test revealed that there was a significant difference in all the conditions except when LEDs were in the Red-Blue (RB) condition changing to Red-Green-Blue (RGB); these results are shown in Table 5.11 and illustrated in Figure 5.16.

Table 5.11 T-Test initial response times as the number of LEDs increases from 1 to 2 to 3 LEDS in the incompatible arrangement.

	T-TEST WHEN LEDS INCREASE (INCOMPATIBLE)		
	Red-Green LED	Red-Blue LED	Red-Green-Blue LED
Red LED	$p < 0.05$	$p < 0.05$	$p < 0.001$
Blue LED	-	$p < 0.001$	$p < 0.05$
Green LED	$p < 0.05$	-	$p < 0.001$
Red-Green LED		-	$p < 0.001$
Red-Blue LED	-		n.s

n.s = not significant

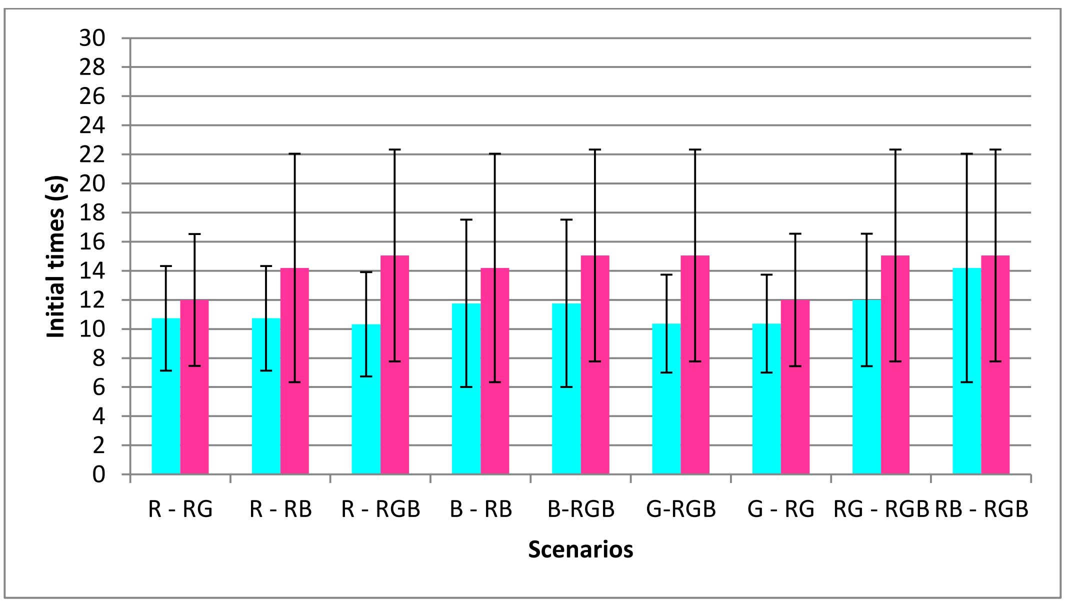


Figure 5.16 T-Test results of initial response times as the number of LEDs increases in the compatible arrangement.

Another paired t-test was conducted on initial response times between the single LEDs only in the compatible and incompatible arrangements. In the compatible arrangement, on average, participants experience faster initial response times in the Green (G) combination than Red (R) and Blue (B) combination. These differences are shown in Table 5.12 and illustrated in Figure 5.17. However, no significance was found between Red (R) and Blue (B) combination. These can suggest that the position of the Blue (B) combination (under the hob) might not help the user using a cooker stove unless Blue (B) shows a specific task to be performed.

Table 5.12 T-Test of initial response times between single LEDs in the compatible LED arrangement.

	T-TEST FOR SINGLE LEDS (COMPATIBLE)		
	Red LED	Blue LED	Green LED
Red LED		n.s	$p < 0.05$
Blue LED	n.s		$p < 0.001$
Green LED	$p < 0.05$	$p < 0.001$	

n.s = not significant

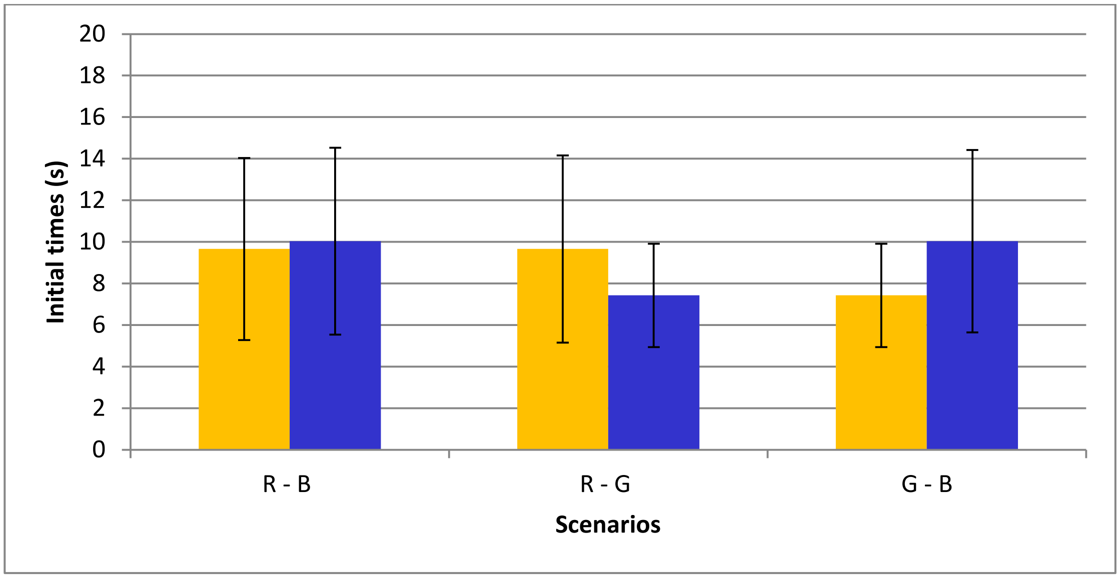


Figure 5.17 Mean initial response times of single LEDs in the compatible arrangement.

In the incompatible arrangement as Table 5.13 and Figure 5.18 illustrate, on average participants experience faster initial response in the Green (G) LED combination compared to the Blue (B) LED combination. Initial response times were slower in the Red (R) combination than Blue (B) combination and initial response times were slightly slower in the Green (G) combination than initial response times in the Red (R) combination.

Table 5.13 T-Test initial response times between single LEDs in the incompatible LED arrangement.

	T-TEST FOR SINGLE LEDS (INCOMPATIBLE)		
	Red LED	Blue LED	Green LED
Red LED		n.s	n.s
Blue LED	n.s		$p < 0.05$
Green LED	n.s	$p < 0.05$	

n.s = not significant

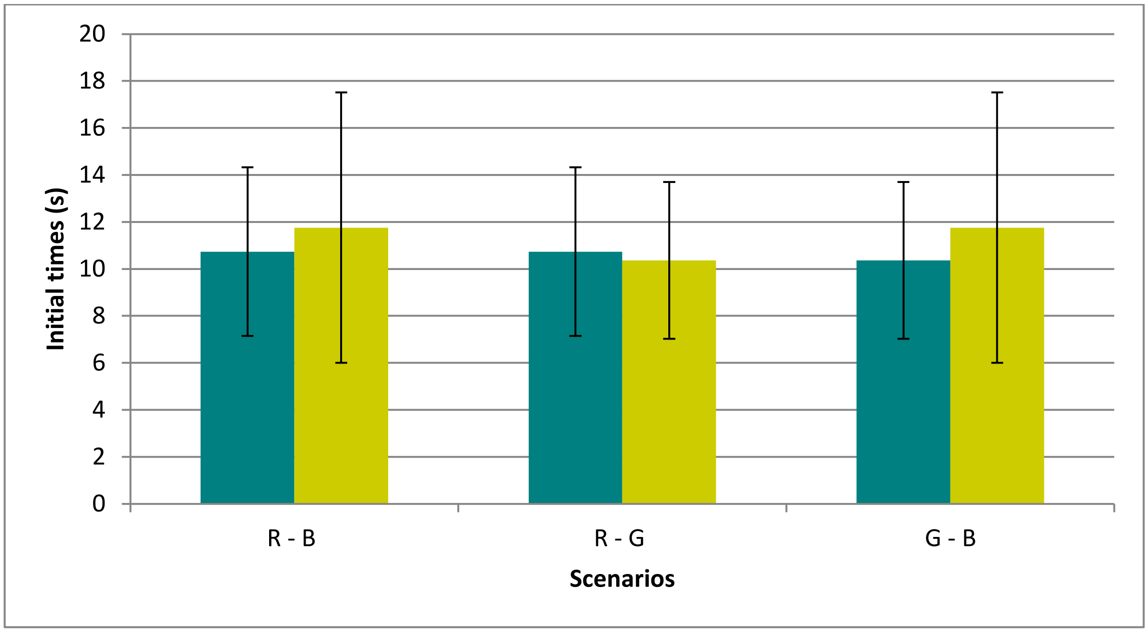


Figure 5.18 Means initial response times of single LED in the incompatible arrangement.

5.3.2.2 Summary of Initial Response Times

Findings of initial response times show that response times are slower in the compatible Red and Blue LEDs where it is expected to be faster as participants become familiar with the burner. But, results have shown that there are no differences in initial response times between Red and Blue LEDs. However, when giving green LEDs condition to participants, initial response times are faster than other single LEDs; this suggests that spatial compatibility between the green LED and controller improves the response times.

Meanwhile, as the number of LEDs increases, the initial response times are faster than initial response times in the single LEDs in the compatible arrangements. However, as the number of LEDs increases in the incompatible, initial response times are slower than any other LED combination.

5.3.3 Correct Response Times

Correct response time was the time when the participant turned the correct rotary knob. Two-way ANOVA was used to measure two independent variables: ***compatibility*** (compatible and incompatible) and ***conditions*** (red, blue, green, redGreen, redBlue and redGreenbBlue). These two independent cross over with dependent variables; ***correct response times*** with thirty-two (32) different participants were used in each condition.

Results from this two-way ANOVA showed that there was significance on the test of homogeneity of variance (see Table 5.14). For the number of attempts, the variance was significantly different between the compatible and incompatible, $F(1, 382) = 30.37$, $p < 0.01$.

Table 5.14 Test of Homogeneity of Variance

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Correct_Times	Based on Mean	30.374	1	382	.000
	Based on Median	19.996	1	382	.000
	Based on Median and with adjusted df	19.996	1	341.217	.000
	Based on trimmed mean	27.786	1	382	.000

There was a significant main effect of the compatibility of LEDs on the correct response times, $F(1, 372) = 98.98$, $p < 0.001$ $\eta^2 = 18.06$. Results also show that there was a significant main effect of conditions on the correct response times, $F(5, 372) = 4.42$, $p = 0.001$ $\eta^2 = 3.16$ (see Figure 5.19).

There was a significant interaction effect between the compatibility of the LEDs' arrangement and the conditions of LEDs, on the correct response times $F(5, 372) = 3.84$, $p = 0.002$, $\eta^2 = 2.62$. This indicates that conditions of LEDs were affected differently by compatibility of LEDs. Figure 5.20 illustrates the interaction graph between compatibility and combination of these contrasts

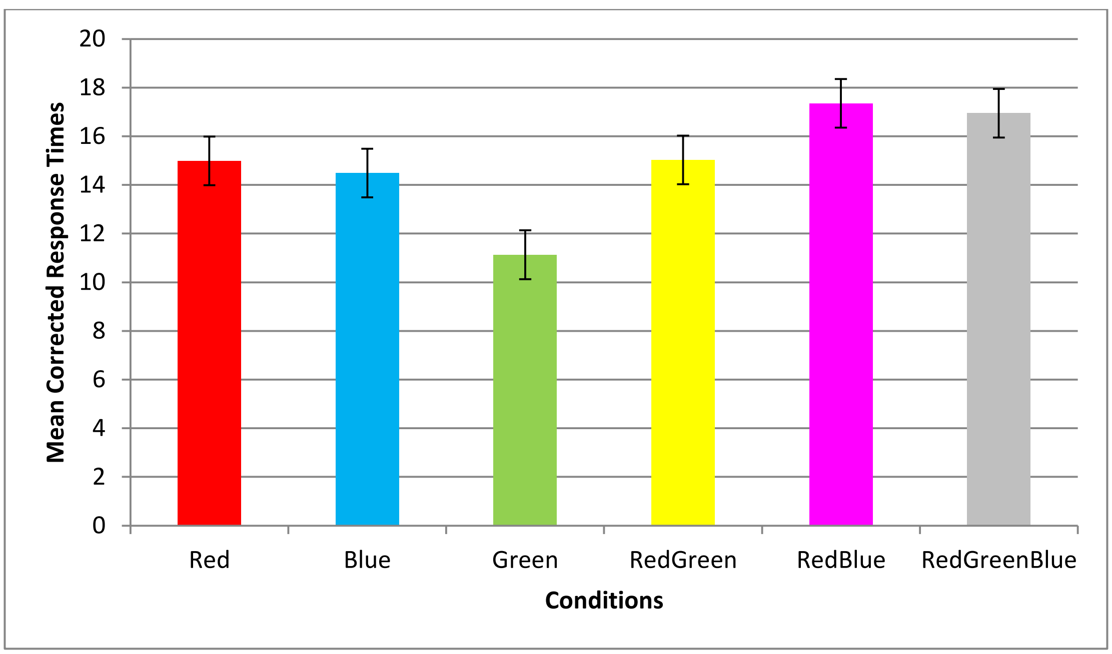


Figure 5.19 Correct response times between conditions.

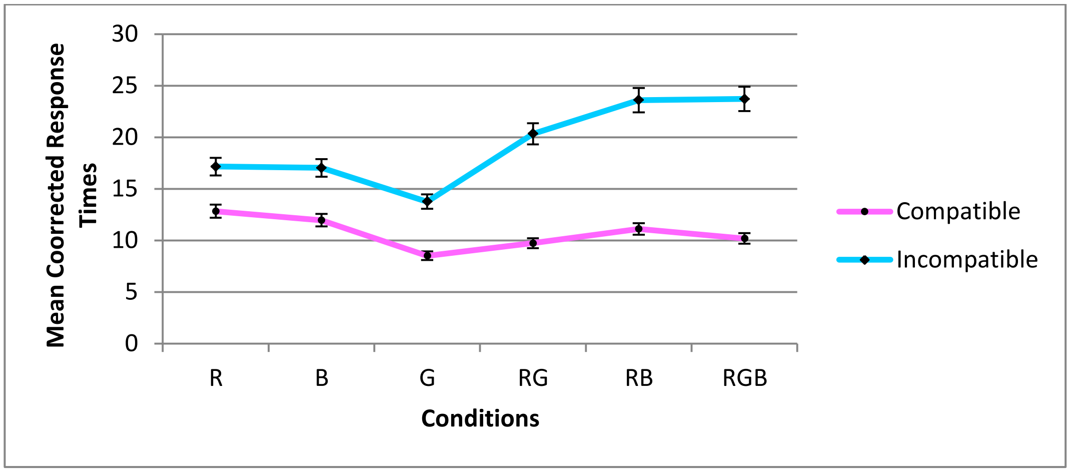


Figure 5.20 Graph of interaction of compatibility and condition in correct response time

The LSD and Bonferroni *post hoc* test revealed that the correct response times were significantly faster in Green ($p = 0.05$) after compared with red, blue, redGreen, redBlue and redGreenBlue conditions. Results also show all conditions were significant when compared with the green condition. Table 5.15 illustrated the results.

Table 5.15 Contrasting correct response times between all conditions.

	Conditions					
	Red	Blue	Green	Red-Green	Red-Blue	Red-Green-Blue
Red		n.s	n.s	n.s	n.s	n.s
Blue	n.s		p = 0.031	n.s	n.s	n.s
Green	n.s	p = 0.031		n.s	p = 0.002	p < 0.001
Red-Green	n.s	n.s	n.s		*n.s*	n.s
Red-Blue	n.s	n.s	p = 0.002	*n.s*		n.s
Red-Green-Blue	n.s	n.s	p < 0.001	n.s	n.s	

The first contrast revealed no significant interaction between incompatible and compatible arrangements when the LEDs' position was in Blue (B) compared to the LEDs' position in the Red (R) combination.

The second contrast compared incompatible to compatible arrangement when the position of LEDs was in the Green (G) combination compared to when the position was in the Red (R) position. This tells us that from the interaction graph (Figure 5.21), corrected reaction times in the Red (R) combination were slower both in the compatible and incompatible arrangement, but as the position of LEDs change to Green (G) combinations, correct response times were faster than the Red (R) combination both in the compatible and incompatible arrangements. There was no significance.

The third contrast revealed a significant interaction when comparing incompatible arrangements to compatible arrangements when LEDs were in the Red-Green (RG) combination compared to when LEDs were in the Red (R) combination, which indicates that correct response times in the Red-Green (RG) combinations were faster than Red (R) combination in the compatible arrangement but slower in the incompatible arrangement.

The fourth contrast compared the incompatible arrangement to compatible arrangement when LEDs were in the Red-Blue (RB) combination to when LEDs were in the Red (R) condition which showed a significant interaction effect. The interaction graph showed that when LEDs were in the Red-Blue (RB) condition, correct response times were faster than in the Red (R) combination in the compatible arrangement but slower when in the incompatible arrangement.

The last contrast revealed a significant interaction when comparing correct responses in incompatible arrangement to compatible arrangement when LEDs were in the Red-Green-Blue (RGB) combination to Red (R) combination. This indicates to us that correct response times in the RGB were faster than in the Red (R) when LEDs were in the compatible arrangement. However, for LEDs in the incompatible arrangement, correct response times in the RGB were slower than in the Red (R) combination.

Then, a series of paired T-Tests were conducted between compatible and incompatible conditions for correct response time. The results showed that on average correct response times in the compatible arrangement were faster than the response times in the incompatible arrangements. These results were significant in all the combinations. Table 5.16 illustrates these results.

Table 5.16 T-Test correct response times between compatible and incompatible LEDs arrangement.

	Conditions					
	Red	Blue	Green	Red-Green	Red-Blue	Red-Green-Blue
Red		n.s	n.s	n.s	n.s	n.s
Blue	n.s		p = 0.031	n.s	n.s	n.s
Green	n.s	p = 0.031		n.s	p = 0.002	p < 0.001
Red-Green	n.s	n.s	n.s		*n.s*	n.s
Red-Blue	n.s	n.s	p = 0.002	*n.s*		n.s
Red-Green-Blue	n.s	n.s	p < 0.001	n.s	n.s	

n.s = not significant

Another series of paired T-Tests was conducted for the correct response times when the number of LEDs increases in the compatible arrangements. Results showed on average as the number of LEDs increases from 1 to 2 LEDs, correct response times of 2 LEDs were faster than single LEDs except in the Green (G) to Red-Green (RG) pairs in which RG's times were slower than the Green (G) combination. Results showed that there was a significant difference between Red (R) and Red-Green (RG) combinations and Green (G) and Red-Green (RG) combinations but no significant difference was found between the Red (R) and Red-Blue (RB) and Blue (B) and Red-Blue (RB) combinations.

Meanwhile, when the number of LEDs increases from 1 to 3, on average correct response times were slower than single Red (R) LED combination, but there was no significant effect found between the Red (R) and Red-Green-Blue (RGB) combination and between the Blue (B) and

Red-Green-Blue (RGB) combination and there was significant difference between the Green (G) and Red-Green-Blue (RGB) combinations.

In the meantime, as the number of LEDs increases from 2 to 3; correct response times of Red-Green-Blue (RGB) were slightly slower than Red-Green (RG) combinations and correct response times in the Red-Green-Blue (RGB) were faster than Red-Blue (RB) combinations. But there was no significant difference found in any 2 to 3 LED combination pairs. These results are shown in Table 5.17 and illustrated in Figure 5.21

Table 5.17 T-Test correct response times as number of LEDs increases in the compatible LED arrangement.

	T-TEST WHEN LEDS INCREASE (COMPATIBLE)		
	Red-Green LED	Red-Blue LED	Red-Green-Blue LED
Red LED	$p < 0.05$	n.s	n.s
Blue LED	-	n.s	n.s
Green LED	$p < 0.05$	-	$p < 0.05$
Red-Green LED		-	n.s
Red-Blue LED	-		n.s

n.s = not significant

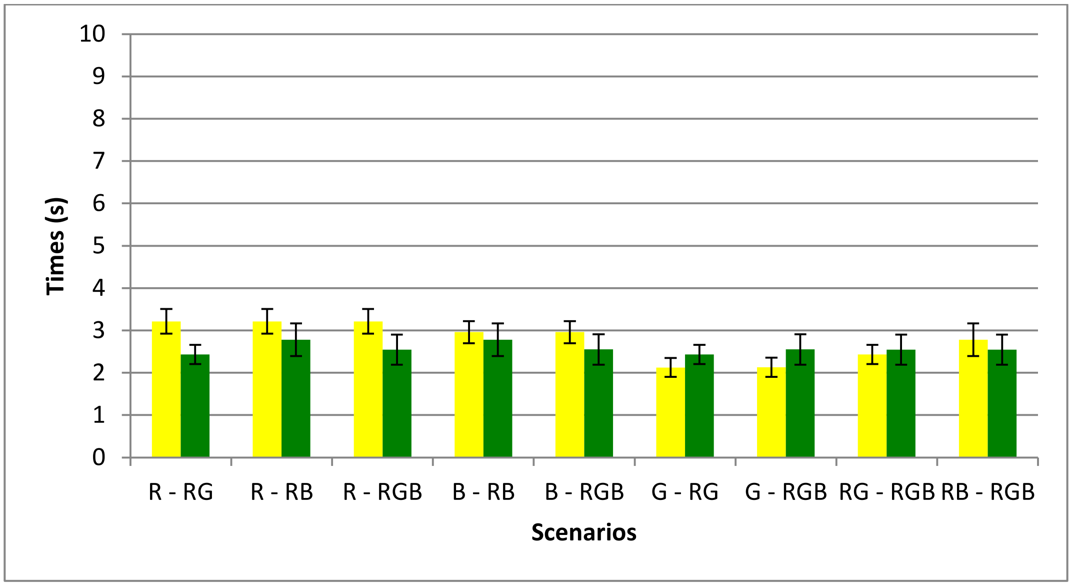


Figure 5.21 Average correct response times as number of LEDs increase in the compatible arrangements.

In the incompatible arrangements, as Table 5.18 shows, a repeated T-Test was conducted on correct response times as the number of LEDs increases. On average, as the number of LEDs increases from 1 to 2 LEDs, correct response times of 2 LEDs were slower than the single LEDs. These were significant in all the 1 to 2 LED combination pairs; Red (R) to Red-Green (RG); Red (R) to Red-Blue (RB); Blue (B) to Red-Blue (RB) and Green (G) to Red-Green (RG) combination. These results can be seen in Appendix E.

As the number of LEDs increases from 1 to 3 LEDs, on average, correct response times of 3 LEDs were slower than single LEDs; there was a significant difference between Red (R) and Red-Green-Blue (RGB); Blue (B) and Red-Green-Blue (RGB) combinations; Green (G) and Red-Green-Blue (RGB). Meanwhile, as the number of LEDs increase from 2 to 3 LEDs, average correct response times in the 3 LEDs were slower than the 2 LEDs; which shows a significant difference between the Red-Green (RG) to Red-Green-Blue (RGB) combination but no significant difference found between Red-Blue (RB) to Red-Green-Blue (RGB) combination. These results are shown in Table 5.18 and illustrated in Figure 5.24.

Table 5.18 T-Test correct response times as number of LEDs increases in the incompatible arrangements.

	T-TEST WHEN LEDS INCREASE (INCOMPATIBLE)		
	Red-Green LED	Red-Blue LED	Red-Green-Blue LED
Red LED	$p < 0.05$	$p < 0.05$	$p < 0.05$
Blue LED	-	$p < 0.001$	$p < 0.05$
Green LED	$p < 0.001$	-	$p < 0.001$
Red-Green LED		-	$p < 0.05$
Red-Blue LED	-		n.s

n.s = not significant

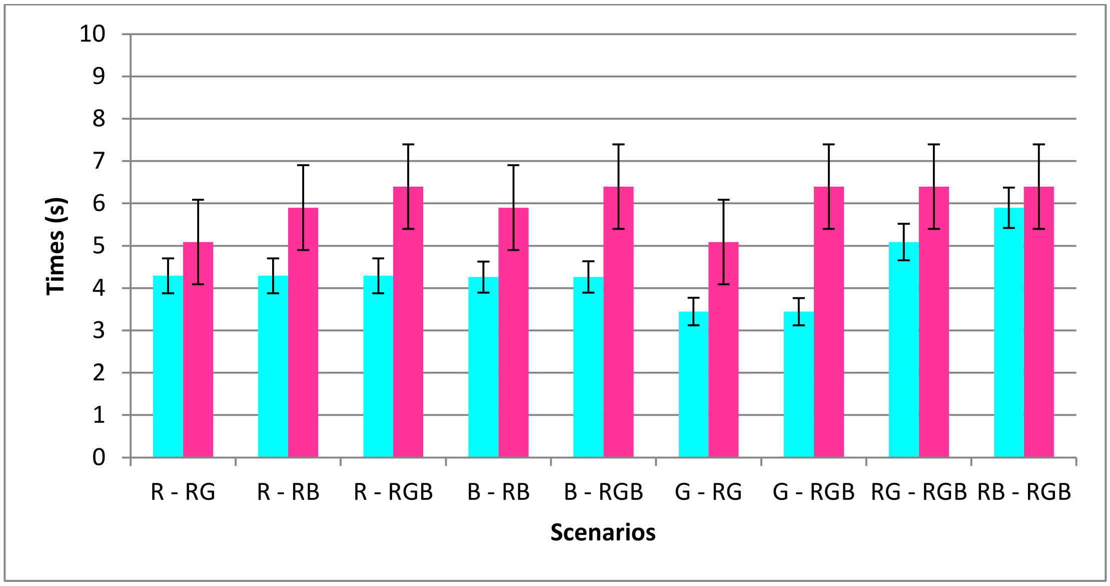


Figure 5.22 Average correct response times as number of LEDs increase in the incompatible arrangements.

Then, a series of paired T-Tests were conducted for the corrected reaction times for single LEDs, Red (R), Blue (B) and Green (G) in both compatible and incompatible condition arrangements.

In the compatible arrangements, the results in Table 5.19 show that correct response times were faster in the Green (G) LED combinations compared to Red (R) LED combinations and this showed a significant difference. On the other hand, correct response times of Blue (B) LED combinations were slower than Green (G) LED combinations and showed a significant difference. Meanwhile, on average correct response times in the Blue (B) LED combinations were slightly faster than Red (R) LED combinations but no significant differences were found. These results are illustrated in Figure 5.23.

Table 5.19 T-Test correct response times on single LEDs in the compatible arrangements.

	T-TEST FOR SINGLE LEDS (COMPATIBLE)		
	Red LED	Blue LED	Green LED
Red LED		n.s	$p < 0.001$
Blue LED	n.s		$p < 0.001$
Green LED	$p < 0.001$	$p < 0.001$	

n.s = not significant.

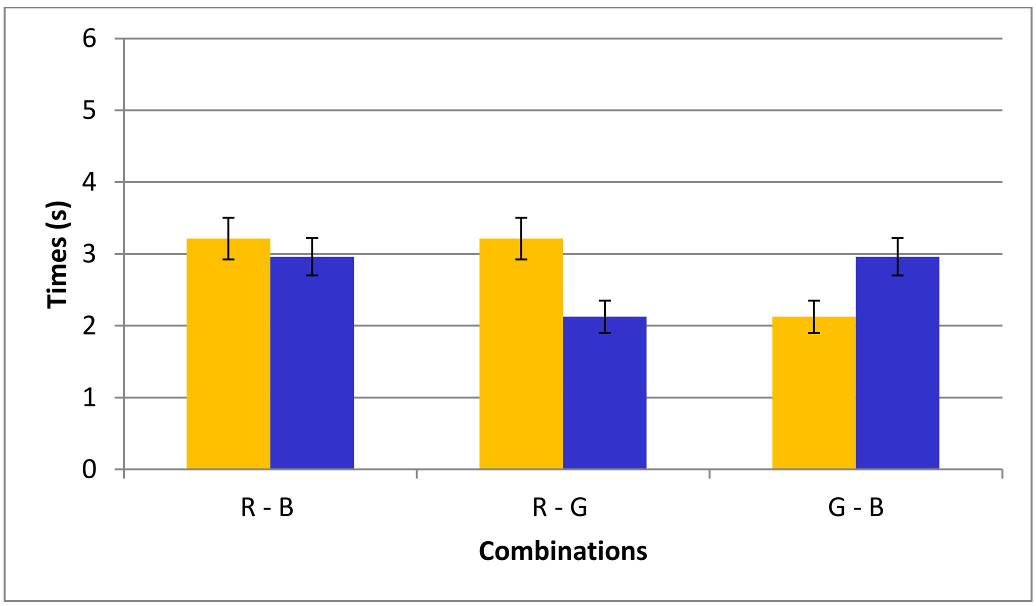


Figure 5.23 Average correct response times between the single lights in the compatible arrangements.

Meanwhile, in the incompatible arrangements, on average correct response times of Blue (B) combinations were slightly slower than Red (R) combinations; no significant difference has been found as the results show in Table 5.20. Correct response times in the Green (G) LED combinations were faster than Red (R) combinations, and show significant difference. Results also showed correct response times in the Blue (B) LED combinations were slower than the Green (G) LED combinations with a significant difference. Figure 5.24 illustrates these results.

Table 5.20 T-Test correct response times on single LEDs in the incompatible arrangements.

	Red LED	Blue LED	Green LED
Red LED		n.s	$p < 0.001$
Blue LED	n.s		$p < 0.05$
Green LED	$p < 0.001$	$p < 0.05$	

n.s = not significant

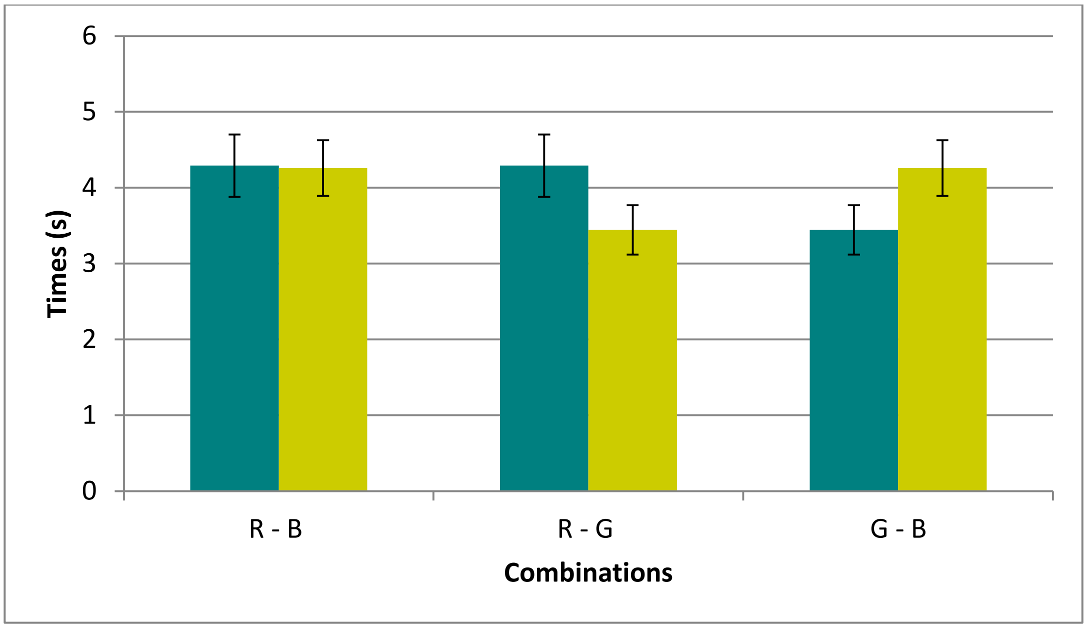


Figure 5.24 Average corrected response times between single lights in the incompatible arrangements.

5.3.3.1 Summary of Correct Response Times

The results of correct response times show that response times of green LEDs are faster than red and blue LEDs. As the number of LEDs increases in the compatible arrangements, response times are faster than red and blue LEDs; however response times are only faster when the LEDs are in the red-green combination. With that, there are no significant response times when LEDs are in the red-blue LEDs combination. This suggests that green LEDs in the Red-Green LED combination do enhance performance by supporting the Red LEDs and the response times are faster. While blue LEDs in the Red-Blue combination do not help or support the performance, which suggests that the position of Blue LEDs does not give benefits during these combinations.

Meanwhile, in the single LEDs (red, blue and green), results of correct response times, green LEDs in the compatible arrangement are faster than red and blue LEDs. In the incompatible arrangement, response towards green LEDs is still faster than Red and Blue even though the response times are slower than in the compatible arrangement by a difference of 2 seconds. Both Malaysian and British participants respond faster when LEDs are in the compatible arrangement but slower when LEDs are in the incompatible arrangements.

5.4 Discussion

The results of this study demonstrate that spatially compatible ambient cueing gives the best performance in terms of fewer attempts to turn the correct rotary knob and faster response times. These results are consistent with Hypothesis 1, i.e. fewer attempts are made in the single Green LEDs (position of Green LEDs is parallel with rotary control) compared to either the Red or Blue combination. However, more attempts were made to the Red LEDs than to Blue LEDs. This result might suggest that participants interpreted Red and Blue LEDs as a different set of information, even though both of the lights actually are highlighted to the same object or burners. It might be the case, for instance, that the Red LEDs were interpreted as burners (as intended) but this does not explain why these should produce *more* of a response than their corresponding Blue LEDs.

As the number of LEDs increases to 2 or 3 LEDs, fewer attempts to turn the correct rotary knob were made than attempts to turn the correct rotary knob in the single LEDs of Red (R) and Blue (B). This result supports the prediction of Hypothesis 2 but no significant results have been found in other pairs of LEDs. This suggests that if the number of LEDs increase and conform to spatial compatibility, in this case Green (G) LEDs, response times are faster than the single LEDs or a combination of 2 LEDs without the Green LEDs. However, there was no significant effect with Red-Green (RG), which might suggest that when Green LEDs are combined with Red LEDs, the focus is only on the Green LED and not the others.

This finding is supported by the results of the response times. Both initial and correct response times show that response times of Green LEDs are faster than any combination of LEDs. As the number of LEDs increases from 1 to 2 or 3 LEDs, initial and correct response times are faster than single Red and Blue LEDs. As the number of LEDs increases from 1 to 3, correct response times are faster in the Red-Green LEDs compared to Red LED and correct response times are slower in the Green LED compared to the Red-Green (RG) LED combinations.

When comparing the correct response times in the single LEDs in the compatible and incompatible arrangement, response times are faster in the Green LEDs than Red and Blue LEDs in the compatible arrangement. However, response times between Red and Blue LEDs are roughly the same both in the compatible and incompatible arrangements.

Results show that the incompatible LEDs arrangement not only affects the decision of the cooker control mapping relationship in the paper-pencil test but also in the Ambient Stove. Incompatible arrangements increase the response times both in initial and correct response times. The numbers of attempts are higher in the combinations with incompatible LED arrangements.

Results from this study have proven Hypothesis 5 that more attempts are made when LEDs are in the incompatible arrangement with slower response times compared to compatible arrangements. Finally, the results of all these studies in the chapters show that ambient cueing does improve performance when there is a compatible arrangement between LEDs and the rotary set. Spatial compatibility does improve performance. There are no significant main effects of nationality in any of the tests. This suggests that there are no performance differences which could be attributed to cultural differences. However, care must be taken with this interpretation for two reasons. First, the gender balance between the two groups is highly skewed, i.e., the Malaysian group was mostly female and the British group was mostly male. This could have led to differences due to gender rather than nationality; although the lack of difference can, equally, be used to suggest no gender differences. Second, the Malaysian participants had been studying in the UK and this would have exposed them to cooker-control arrangements which were different to those they were familiar with. This could mean that the lack of difference illustrates an homogeneous level of experience with the type of cooker control arrangement that are common in the UK.

5.5 Conclusion

This is the end of simple ambient studies. From Chapters 3 to 5 of this study, we can conclude that using visual cues such as ambient display does enhance and improve performance if the LEDs or a combination are in compatible arrangements. Findings in the questionnaire studies show that without concerns of cross-cultural differences, Linkage IV becomes the preferred linkage in the single LEDs (red and blue LEDs), while Linkage III becomes the preferred linkage when the number of LEDs increases to 2 and 3 LEDs in the compatible arrangements.

While in the incompatible arrangements, responses towards the control-burner linkages are varied.

When repeating the test with two different cultures; Malaysian and British, cooker-control linkage preferences are split between Linkage III and IV by Malaysian participants in the Red and Blue LEDs combination, while British participants respond to Linkage III (Red LEDs) and Linkage IV (Blue LEDs). As the number of LEDs increases to 2 or 3 LEDs, Malaysian and British participants respond to Linkage III but it is not the same percentage of responses by British participants to Linkage II and V in the compatible Red-Green-Blue combination. Consistent with a study in Chapter 3, linkage preferences in the incompatible arrangements are varied.

Taking further the questionnaire study, four burner stove hardware prototypes have been developed and tested in this chapter. The prototype is used to measure the number of attempts and the response times when given an ambient cueing to respond to. Spatial compatibility shows the numbers of attempts are lower and response times are faster (in this case when green LEDs are in line with the rotary knob). As the number of LEDs increases to 2 or 3, response times are faster than single LEDs and fewer attempts are made if the arrangements are in the compatible arrangements. However, if the LEDs are in incompatible arrangements, performances are worse and actually slow down the activity.

The results are different from previous studies and indicate that testing control-burner linkages does give different results from others. We argue that the results in the present study are more solid than the previous ones, as visual cues do not have a suggestive effect which is found in most of the previous studies. Moreover, results in this study support the current HCI development of ubiquitous computing in the digital environments, which implement embedded and invisible technologies behind the walls.

CHAPTER 6

Complex Ambient Cueing in the Digital Kitchen

While the previous three chapters investigated a *simple* ambient display as a means for supporting decisions on which control to use (following the principles of Stimulus-Response Compatibility), this chapter explores and extends the approach of the potential of *complex* ambient cueing in the digital kitchen. The chapters exploring a simple ambient display suggested that increasing the amount of information (in the form of providing multiple cues to the user) *could* enhance performance as long as there was no incompatibility in the cues they provided. Thus, redundancy in cueing was seen to have the potential to be beneficial under some conditions. However, when the cues did not agree with each other, then performance was far worse when there were multiple cues. Taking this point further, it is proposed that if the cues do not agree with the expectations or knowledge of the user, then performance could be equally compromised. Evaluating the benefits of ambient cueing through user trials will help to better understand the behaviour of users in order to produce a ‘problem list’ which will be valuable in improving of the usability of the ambient displays in the near future. This study addresses three questions.

(i) How do different interaction styles affect performance with ambient cueing?

From the view of current applications in ambient kitchens in particular and ambient cueing more generally, one can see that the presentation of media, such as recipe ideas and cooking guidance, are popular concepts. We have developed our application based on these concepts. On the one hand, an ‘ambient’ interface ought to respond to the user’s actions; e.g., when they pick up an item, there should be the opportunity to receive feedback and guidance relating to the cooking tasks. On the other hand, the user might wish to retain some control over the presentation of feedback (so that they are not continually interrupted during their activities). This challenge of balancing the need to incorporate feedback and guidance with the cooking tasks was addressed through the development of two forms of user interface.

Borrowing from traditional Human-Computer Interaction (HCI) approaches to interaction design, there is an ‘indirect’ form (in which the user points to specific items to receive information) and a ‘direct’ form (in which interaction with objects in the environment results in the presentation of information). By way of analogy, the ‘indirect’ form is like the use of a mouse to control a cursor on the screen to point at the object to select, and the ‘direct’ form is like the use of a touchscreen to select the object. One argument in favour of the ‘direct’ interface is that it allows the user to merge the selection of objects with their current task, while the ‘indirect’ interface means that they stop one task in order to do a new task, i.e., move their hand from the keyboard to move the mouse, thus interrupting typing.

In this study, both user interfaces involved the projection of the information onto the surface on which the person was working. Finally, as a control condition, a paper ‘recipe book’ was created to display instruction on a step-by-step basis to participants. This was presented in order to compare the ambient cueing with a ‘conventional’ mode of acquiring information in the kitchen. Thus the user trial involved participants completing the tasks using one of three distinct user interfaces.

(ii) Do different levels of skill benefit from ambient cueing?

While the projected displays might present guidance on recipes and cooking activity, it is plausible to assume that people who are skilled in the cooking task would find such displays intrusive, patronising and unhelpful. Thus, the experiments should involve participants who were familiar with the recipes being presented and had a high level of (self-diagnosed) cooking proficiency, compared with participants who were unfamiliar with the recipes and who had a relatively low level of (self-diagnosed) cooking proficiency.

(iii) Do differences in interaction styles and cooking tasks affect different skills levels?

In addition to the usefulness of the information displayed, it might be possible that the different interaction styles will have different impacts on the ‘skilled’ and ‘unskilled’ cooks in this study, e.g. in terms of the manner in which the tasks are supported or interrupted.

6.1 Design and Hypotheses

In this study, a functional prototype (with information presented using PowerPoint) was designed to ‘assist’ the user performing a cooking activity in a kitchen environment. This is projected on top of the table by an LCD projector. Figure 6.1 shows the arrangement of equipment used in the experiment in this study.

Before the task, the ingredients are placed in small, ceramic containers and arranged on the table. This layout provides a convenient structure for the projections. The short survey in Chapter 1 showed that people prefer to prepare ingredients prior to cooking them, and these prepared ingredients are often laid out on the work surface. Accordingly, we laid ingredients out on the work surface for this study. It is not suggested that a ‘real’ kitchen would be so regimented (although, of course, cooking on television programmes is often performed with all the ingredients prepared and placed around the TV Chef). However, the layout meant that all participants were confronted with exactly the same arrangement with all ingredients and utensils positioned in the same places prior to the start of the trials. This meant that the arrangement of the work surface was consistent across all trials.

Figure 6.1 Arrangement of experiment set-up

The display layout was divided into four sections which are ‘workspace’, ‘instructions’, ‘ingredients’ and ‘utensils’. The *workspace* is where the user performs the cooking task, while the *instructions* space is where all the instructions and icons are listed. On the left of the layouts, is the *ingredients* space where 24 real ingredients are displayed, and on the right side is the *utensils* space where all the equipment and tools are placed. The layout of these sections is illustrated in Figure 6.2.

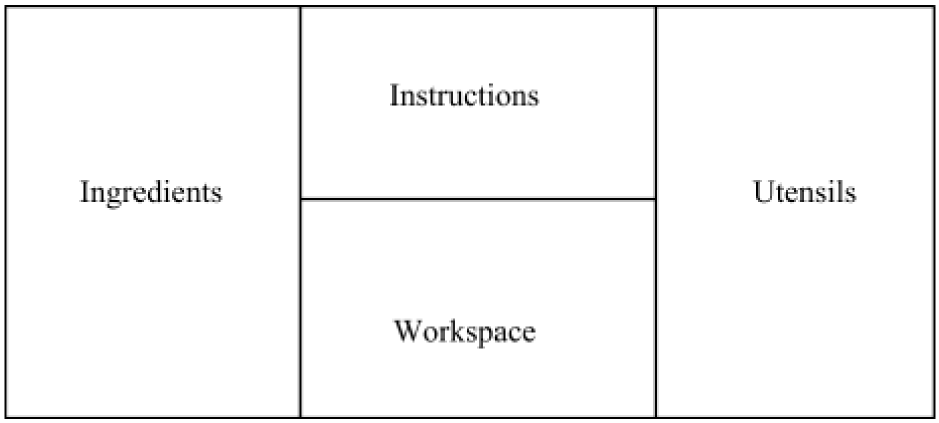


Figure 6.2 The layout of the work surface for this experiment

It is worth pointing out that the 'actions' performed by participants did not involve any real cooking tasks and did not include heating the food. Discussions with the school's Health and Safety supervisor meant that it was not possible to do any actual cooking in the laboratory. This was naturally disappointing and alternatives were discussed, e.g. in terms of positioning the projector in a real kitchen. However, it was further pointed out that such a set-up would still be covered by Health and Safety requirements and in the absence of a purpose-built environment for this work, the solution was to have participants undertake cooking tasks which were primarily concerned with combining the ingredients. It was felt that this was a reasonable compromise, given that the focus of this study was on how people interacted with ambient cueing rather than on cooking *per se*.

Within the *instruction* space, there are four icons which participants can use to request 'more' information by pointing to or tapping the icon:

- *Ingredients* will list ingredients needed;
- *Utensils* will list tools to be used;
- *Video* shows 'how to-do' the step if unsure, and
- *Next* will display the next step to be performed.

6.1.1 Media and Conditions

Three different types of user interface were designed to test the user performance in the cooking task in this study; *recipeBook*, *ambient* and *smartChalk*. Similar to a traditional cookery book, the *recipeBook* is a printed document which contains information on cooking. It contains a collection of recipes that provides step-by-step instructions, lists the ingredients required and their quantities. *recipeBook* required participants to read and follow the instructions given to complete the cooking task. Figure 6.3 shows the experiment trials in the *recipeBook*.

Figure 6.3 ***recipeBook***

Ambient is a recipe book that is projected on top of the table. This provides step-by-step instructions as a guided digital information cook book through ambient display. It is inspired by the example of digital cookbooks discussed in the literature review, Section 2.4 in Chapter 2. *Ambient* allows participants to request information by tapping the icons and when the participant touches (i.e. places their hand on or next to) an ingredient or utensil, a coloured disc is projected on top of the object.

This projected disc indicates whether the ingredient is right or wrong, for that step of the recipe. If it is the right ingredient, a green disc will be projected on top of the ingredient (red when the ingredient is wrong). It is acknowledged that the most common form of colour blindness involves red and green and this was considered in the selection of the colours – the resulting 'red' colour is much darker than the 'green' and so it is possible to use the coloured discs in terms of light and dark. If the correct ingredient is selected, the name of the ingredient will change to green text at the same time. For the purposes of this trial, the action of the participant is monitored by the experimenter who cues the appropriate information (thus following a standard *Wizard of Oz* approach to prototyping). Figure 6.4 shows the experimental set up in the *ambient* interface.

Figure 6.4 Ambient interface

The *smartChalk* interface uses the same display as *Ambient*, as shown in Figure 6.5. However, *smartChalk* requires participants to interact with the interface by using a small handheld LED-torch. The participant points the LED at the digital information needed. A webcam captures the position of the light and the *smartChalk* software links this to the information required. Thus, while the *ambient* display provides a form of direct interaction (albeit mediated by the 'wizard'), the *smartChalk* represents a form of indirect interaction. While the *ambient* interface was a Wizard of Oz study run by the researcher, *smartChalk* is an off-the-shelf solution supplied by researchers from the *Moscow State Institute of Electronics and Mathematics* who were working in the school at the time of this research. Figure 6.5 illustrates the *smartChalk* user interface.

Figure 5.5 smartChalk interface

6.1.2 Cooking Recipes

This experiment involved simulated cooking activity of two Malaysian recipes: *Fish Curry* and *Pandan Chicken*. Each recipe is broken down into two sub-tasks; *prepare curry paste* and *cook* *fish* for Fish Curry and *prepare chicken* and *cook chicken* for Pandan Chicken. The purpose of using two different cooking tasks is to test the effect of level of complexity for each user interface. Complexity of the tasks is defined by the number of steps, number of different actions, number of ingredients and number of different tools (see Table 6.1). Preparing curry paste and cooking fish show a general increase in the number of steps, number of ingredients and number of cooking tasks. Meanwhile, in the *Pandan Chicken* recipe, the complexity of preparing chicken shows a slight increase in the number of steps but a reduction in the number of ingredients and tools. The cook chicken actions involve more advanced cooking skills (although these could not be directly assessed, for the reasons mentioned earlier).

Table 6.1 Relative 'complexity' of task

	Prepare Curry paste	**Cook Fish**	**Prepare Chicken**	**Cook Chicken**
Steps	5	10	6	7
Ingredients	10	14	12	3
Tools	2	3	4	3
Actions	3	5	4	6

6.1.3 Hypotheses

The work in this chapter looked into the impact of the conditions towards user performance and was measured by cooking times, completed number of steps and the number of errors made. Therefore, the following hypotheses were made.

i. **Hypothesis 1 (H1)** The amount of times spending in cooking activities are faster for both 'skilled' and 'unskilled' participants, given the interface provided a direct mapping manipulation.
ii. **Hypothesis 2 (H2)** Direct interactions provided an ease and natural way of interaction given both group of participant performance better in the cooking activities.
iii. **Hypothesis 3 (H3)** Direct interaction provides an error-free interaction which allows users to complete cooking task even with higher cooking complexity.

6.2 Participants and Procedures

Twenty participants were involved in this experiment. Ten participants were from Malaysia and aged from 22 to 35 (6 female and 4 male) and rated themselves as both familiar with the recipes and good at cooking. Another ten participants were drawn from different cultures aged between 19 and 17 years old (8 male and 2 female) and rated themselves as not good at cooking and unfamiliar with the recipes. Malaysian participants were defined as an 'expert' group while the non-Malaysian participants were defined as a 'non-expert' group.

Each participant was given a standard set of instructions at the beginning of the experiment regarding how to perform the cooking activity. The instructions emphasized the following.

- Participation requires completing a task by following the steps and instructions provided.
- Participants are allowed to ask about the task, or ingredients in the *recipeBook* condition but not in the a*mbient* and *smartChalk* interface.
- Participants are to select information using a 'chalk' (small, coloured LED) as a pointing device in the *smartChalk* interface, and act out the cooking task afterwards.

Each participant was required to complete the cooking task within five minutes. Each participant needed to perform all four cooking tasks for each interaction interface (three) giving a total of 12 consecutive trials individually. The cooking tasks were tested on different days with at least a one day gap between the tasks. The orders of cooking activities were randomized across participants. A high resolution digital camera was used to record the cooking activities in this experiment. Following the cooking tasks, the video-recording was coded by hand. Videos were annotated using the ELAN – Language Archiving Technology Software.

6.3 Results

The results analyse the difference between Malaysians and Non-Malaysians in terms of time to complete the task, the time taken to complete each step, steps completed and errors for each of the cooking tasks. Two-tailed statistical has been applied with respective *p-value* divided into two in the T-Test to meet the one-tailed condition which has been explained in Chapter 5.

6.3.1 Cooking Times

A three-way analysis of variance (ANOVA) was conducted to measure two independent variables: ***Interface*** (recipeBook, Ambient and smartChalk) and **task** (curryPaste, cookFish, prepareChicken and cookChicken). These two variables completely cross-over producing twelve (12) experimental conditions between two groups of ***participants***; Malaysian and Non-Malaysian. Cooking times were the times taken to complete the cooking tasks with a maximum of five minutes.

Table 6.2 shows the results of Mauchly's sphericity test for each of the three effects in the experiment (two main effects and one interaction). The significant values of these tests indicate that the interaction *Interface x Tasks* has violated this assumption and so the F-value should be corrected to the Greenhouse-Geisser effect. However, no significant values were found in the main effect; *interface* and *tasks.* Therefore the sphericity assumption has been met.

Table 6.2 Mauchly's Test of Sphericity

Within Subject Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
Interface	0.818	3.413	2	0.181
Tasks	0.719	5.509	5	0.358
Interface * Tasks	0.098	36.727	20	0.014

All effects were reported as significant at $p < 0.05$ except in the interaction effect of *interface x tasks x participants.* There was a significant main effect of participants [$F(1, 18) = 4.509$, $p = 0.048$]. This indicates that cooking times differed between Malaysian and Non-Malaysian participants. There was also a significant main effect of the *interface* [$F(2, 36) = 9.357$, $p = 0.001$] indicating that cooking times were different between *recipeBook*, *ambient*, and *smartChalk* user interface. There was a significant main effect for *task* [$F(2, 36) = 12.001$, $p < 0.001$]. These results are illustrated in Figure 6.6. Subsequent contrast testing revealed that cooking times of *cookChicken* were faster than *curryPaste*, *cookFish* were slower than *curryPaste*, and the time *prepareChicken* were about the same with preparing curry paste. These results are shown in Table 6.3.

Table 6.3 Contrast of completion times of tasks compared to curryPaste task

	Contrast Task			
	Curry Paste	Cook Fish	Prepare Chicken	Cook Chicken
Curry Paste		p = 0.002	n.s	p = 0.001
Cook Fish	p = 0.002			
Prepare Chicken	n.s			
Cook Chicken	P = 0.001			

n.s = not significant

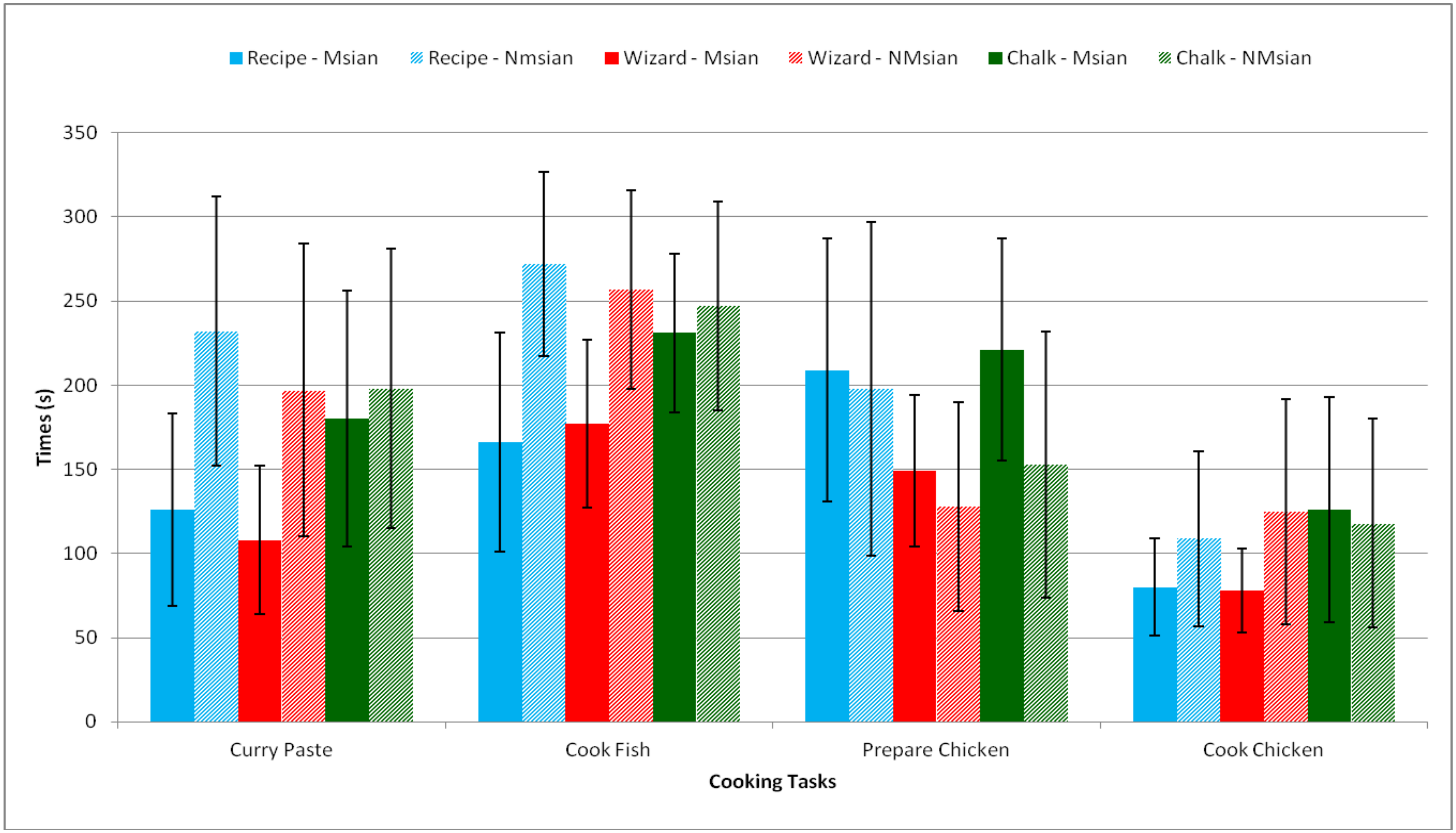


Figure 6.6 Average times taken to complete the cooking task between Malaysian and Non-Malaysian in three different interactions

There was a significant interaction effect between the user interface and groups of participants [$F(2, 36) = 12.001$, $p < 0.001$]. Times differed between Malaysians and Non-Malaysians for the recipeBook and ambient but not for *smartChalk* (Figure 6.7).

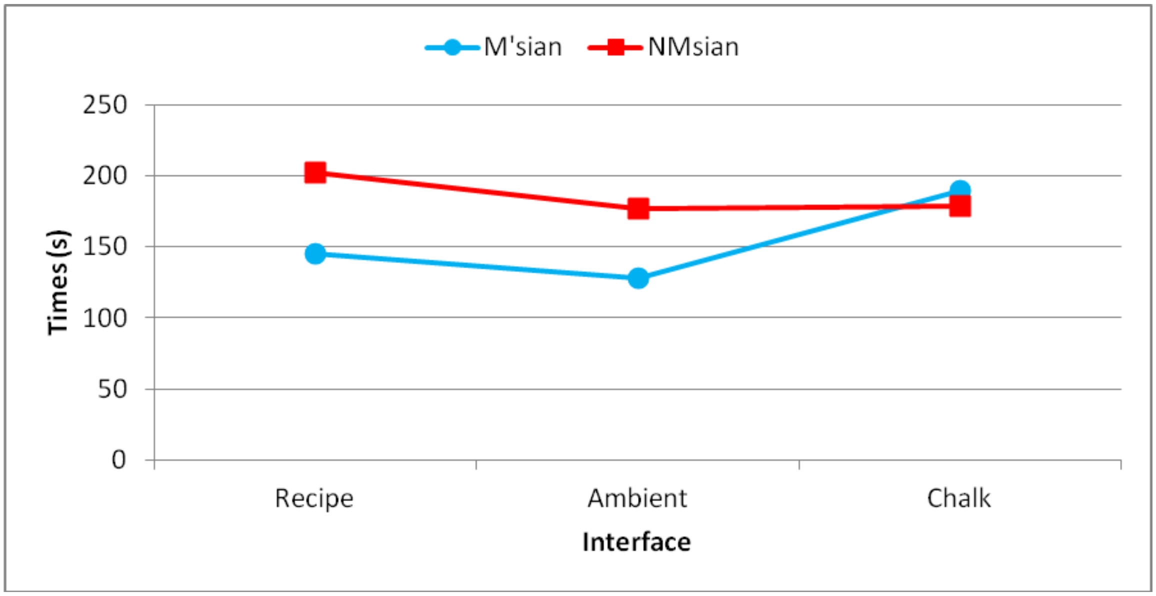


Figure 6.7 Cooking times in the interaction interface across different participants

To break down this interaction, contrasts were drawn, comparing different levels of interaction interfaces to the *ambient* interface across Malaysian and Non-Malaysian participants (Table 6.4). These results showed that Malaysian participants perform faster in the *ambient* and *recipeBook* conditions than Non-Malaysian participants, but that times for Malaysian and Non-Malaysian participants were the same in the *smartChalk.*

Table 6.4 Contrast of completion times across interaction interface to expertise

	Contrast Interfaces x Expertise		
	Recipe Book	Ambient	Smart Chalk
Recipe Book		n.s	
Ambient	n.s		p < 0.001
Smart Chalk		p < 0.001	

Three-way ANOVA also showed there was a significant interaction between cooking tasks and participants [$F(3, 54) = 5.544$, $p = 0.002$]. This indicates that times in the cooking tasks differed between Malaysians and Non-Malaysians. These results are illustrated in Figure 6.8.

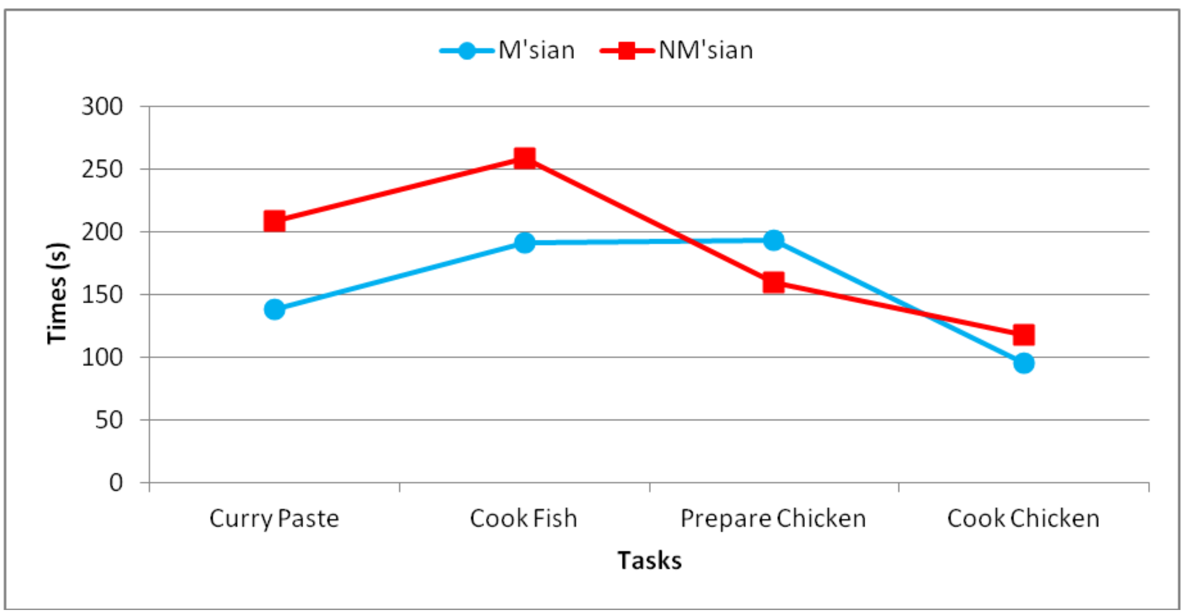


Figure 6.8 Average cooking times in all the cooking tasks between Malaysian and Non-Malaysian participants

To break down this interaction, contrasts were performed comparing each of the cooking tasks to *curryPaste* across Malaysian and Non-Malaysian participants. These revealed a significant (Table 6.5) interaction when comparing Malaysian and Non-Malaysian cooking times of *prepareFish* task to *curryPaste* task but no significant interaction when comparing Malaysian and Non-Malaysian cooking times of *cookChicken* and *cookFish* to *curryPaste*. The interaction graph illustrated in Figure 6.8 show that both Malaysians and Non-Malaysians take a longer time to cook in the *curryPaste* than *cookChicken.*

Further, when comparing times in the *prepareChicken* and *curryPaste*, Malaysian participants took longer to complete than Non-Malaysian participants. Meanwhile, cooking times of *curryPaste* were faster than *cookFish* task regardless of whether the participants were Malaysian or Non-Malaysian. These results are further shown in Appendix F.

Table 6.5 Contrast completion times across cooking times and expertise

	Contrast Cooking Task x Expertise			
	Curry Paste	Cook Fish	Prepare Chicken	Cook Chicken
Curry Paste		n.s	$p < 0.05$	n.s
Cook Fish	n.s			
Prepare Chicken	$p < 0.05$			
Cook Chicken	n.s			

Results showed no interaction effect between user interface and cooking task [F (3.85, 69.32) = 2.429, p = 0.058]. There were no significant interaction effects between interaction interface, cooking task and participants [F (3.85, 69.32) = 0.410, p = 0.794].

Post-hoc, pairwise comparison, using T-Test, revealed no difference in cooking times between the *recipeBook* and *ambient* condition for Malaysians. As SPSS provides only the two-tailed significant value, the sig value is divided by two to get the one-tailed significance. Malaysian participants were significantly slower when using the *smartChalk* compared to the *recipeBook* or *ambient* conditions. Meanwhile, for Non-Malaysian participants, there was a significant difference in the *recipeBook* and *ambient* conditions but no other significance in other conditions. These results are shown in Table 6.6 and illustrated in Figures 6.9 and 6.10.

Table 6.6 T-Test completion cooking times for Malaysian and Non-Malaysian

	T-Test of Cooking Times		
	Malaysian		
	recipeBook	Ambient	smartChalk
recipebook		n.s	p = 0.001
Ambient	n.s		p < 0.001
smartChalk	p = 0.001	p < 0.01	
	Non-Malaysian		
	recipeBook	Ambient	smartChalk
recipebook		p < 0.05	n.s
Ambient	p < 0.05		n.s
smartChalk	n.s	n.s	

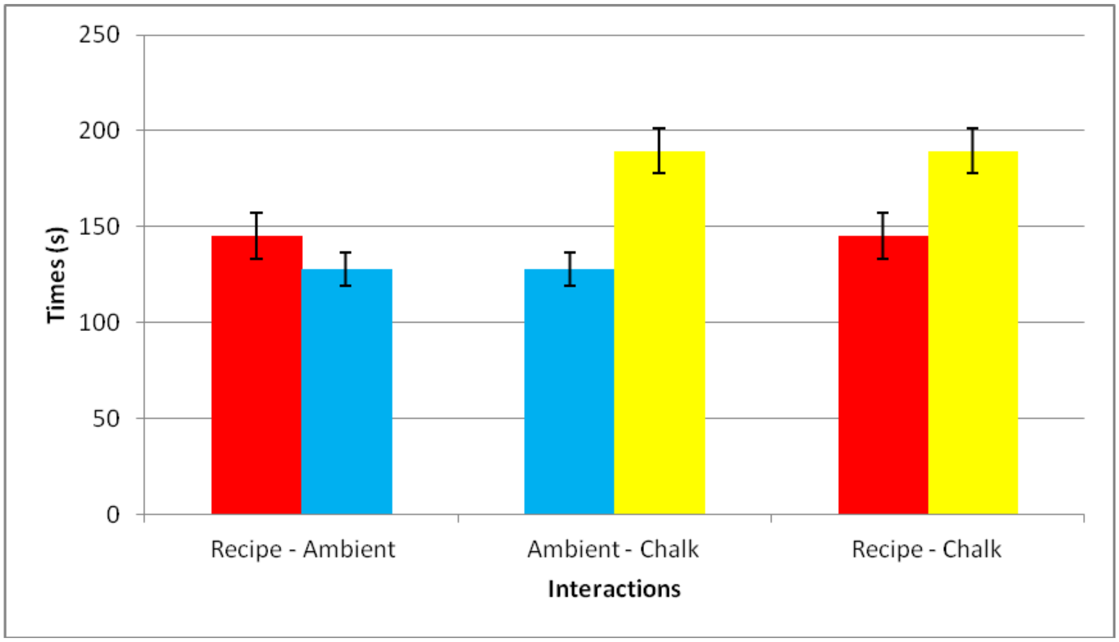


Figure 6.9 Completion cooking times for Malaysian participants

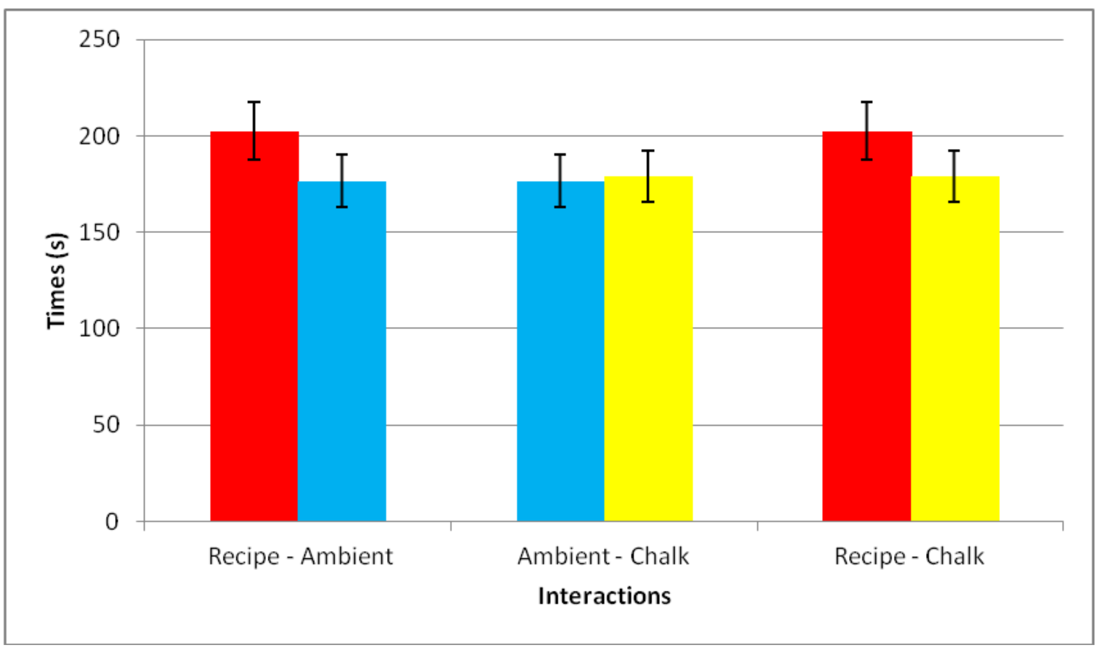


Figure 6.10 Completion of cooking times for Non-Malaysian participants

A T-Test on average cooking times for each interaction interface between Malaysians and Non-Malaysians was conducted. In terms of the interaction of interface and expertise, the T-Test revealed significant differences between Malaysian and Non-Malaysian participants in the *recipeBook* [t (74.61) = 3.019, p < 0.001] and the *ambient* condition [t (66.52) = 2.987, p < 0.001] but no difference for *smartChalk* [t (78) = 0.594, p = 0.277]. These results are shown in Table 6.7 and illustrated in Figure 6.11.

Table .6.7 Test on completion cooking times for all participants

	T-Test of Cooking Times
	Malaysian and Non-Malaysian
recipeBook	p < 0.001
Ambient	p < 0.001
smartChalk	p > 0.05

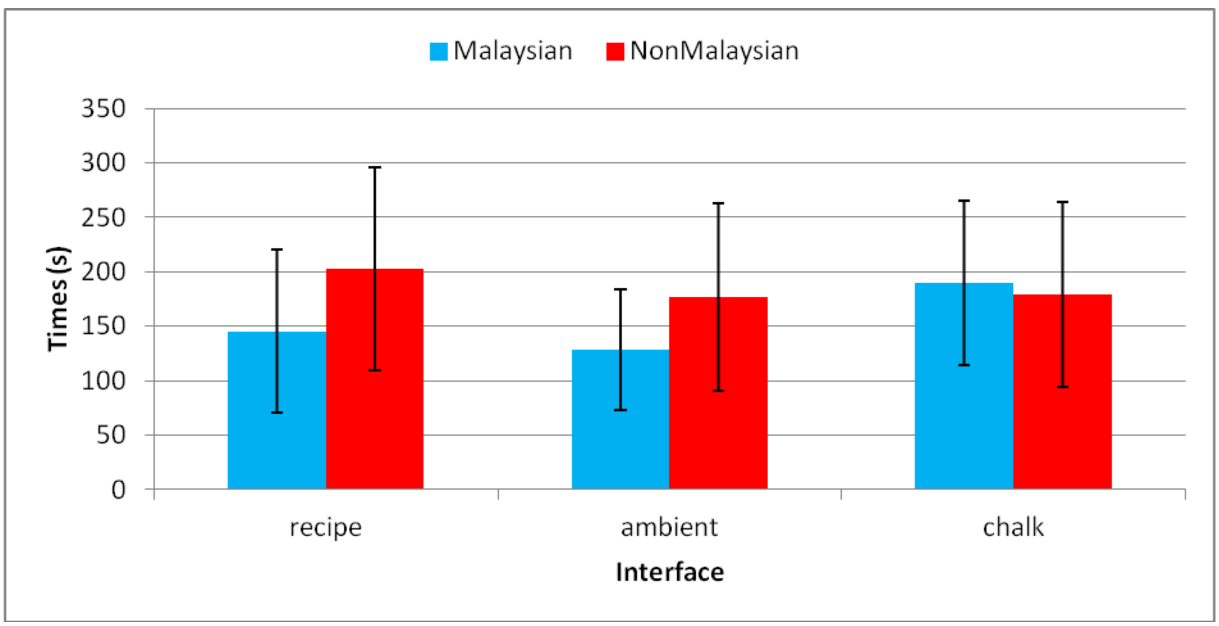


Figure 6.11 Average cooking times taken to complete the cooking task using different interface by Malaysian and Non-Malaysian participants

The expert (Malaysian) participants completed cooking activities faster than Non-Malaysian participants, as one would expect. However, when cooking activities were performed using *smartChalk*, their performance was significantly reduced. This suggests that participants who know the ingredients and recipes could be slowed down by 'indirect' interaction with the information that supports these tasks. Interestingly, in the *ambient* condition, Malaysian participants performed better than in the *recipeBook* condition (which suggests that the differences could be attributed to the interference in task performance that the *smartChalk* introduced rather than the provision of information that they might be expected to already know). In contrast, the 'non-expert' (non-Malaysian) participants took roughly the same time using *ambient* and *smartChalk*. Despite not knowing the recipes and ingredients, the performance by non-Malaysian participants was still better in the *ambient* condition, compared to using the *recipeBook*. This suggests that the *ambient* interaction, providing it does not interfere with cooking tasks, need not hinder the 'expert' and can assist the 'non-expert.'

6.3.2 Number of Steps

A three-way analysis of variance (ANOVA) was conducted to measure two independent variables: ***Interface*** (recipeBook, ambient and smartChalk) and ***task*** (curryPaste, cookFish, prepareChicken and cookChicken). These two variables completely cross over producing twelve (12) experimental conditions between two groups of ***participants***; Malaysian and Non-Malaysian. The numbers of steps were different for each cooking task, which were *curryPaste*

(5), *cookFish* (10), *prepareChicken* (6) and *cookChicken* (7). The analysis was conducted based on percentages of completed steps in each cooking task.

Table 6.8 shows the results of Mauchily's Sphericity test for each of the three effects in the experiment (two main effects and one interaction). The significant values of these tests indicate that both the main effects and interaction, *interface, tasks* and *interface x task,* have violated this assumption and so the F-value was corrected to the Greenhouse-Geisser effect.

Table 6.8 Mauchly's Test of Sphericity

Within Subject Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
Interface	0.480	12.473	2	0.002
Tasks	0.356	17.281	5	0.004
Interface * tasks	0.091	37.791	20	0.011

Three-way ANOVA analysis showed there was no significant main effect due to participants [F (1, 18) = 0.914, p = 0.352]. This indicates that the percentages of steps completed did not differ between Malaysians and Non-Malaysians. Results also show that there was a significant main effect of interface [F (1.32, 23.69] = 52.982, p < 0.001]. This indicates that the percentages of completed steps differed among the *recipeBook*, *ambient* and *smartChalk* user interfaces. These results are illustrated in Figure 6.12.

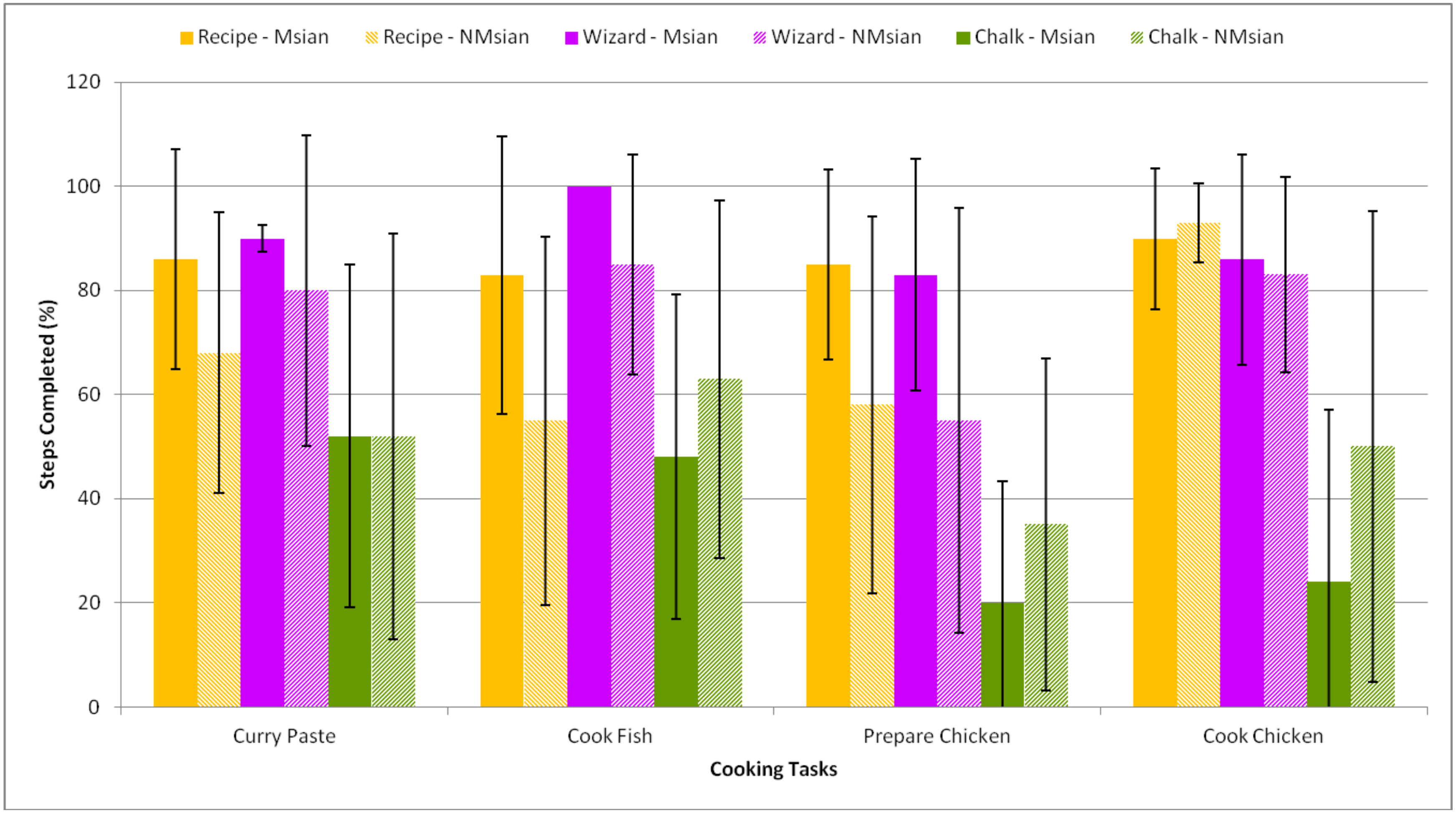


Figure 6.12 Percentage of steps completed in the cooking tasks by Malaysian and Non-Malaysian participants in three different interactions

There were also significant main effects due to task [F (1.97, 35.39) = 3.945, p = 0.042] which indicates that percentage of completed steps differed between cooking tasks. Table 6.9 showed the contrasted results by comparing the completed steps of each cooking task to percentage completed steps of *curryPaste* and show a significant interaction in the *prepareChicken*. There were no significant interaction effect in the *cookChicken* and *cookFish* to *curryPaste* task.

Table 6.9 Contrasted percentage of number of steps completed

	Contrast Percentage Number of Steps Completed			
	Curry Paste	Cook Fish	Prepare Chicken	Cook Chicken
Curry Paste		n.s	$p < 0.05$	n.s

n.s = not significant

There was a significant interaction effect due to interface and participant [F (1.32, 23.69) = 8.465, p = 0.005] which indicates that the steps completed in the user interfaces differed between Malaysian and Non-Malaysian participants. To break this interaction down, contrasts were performed for each user interface across Malaysians and Non-Malaysians.

Contrasted results reveal a significant difference when comparing Malaysian and Non-Malaysian completed steps of *smartChalk* to *ambient* and tell us that percentage steps completed were lower among Malaysians but higher for Non-Malaysians in the *smartChalk* interaction and that, percentages of steps completed were higher in an *ambient* condition among Malaysians but lower among Non-Malaysians. Meanwhile, that there was no significant effect between *recipeBook* and *ambient* interfaces showed that percentages of steps completed were about the same in the *ambient* and *recipeBook* regardless of Malaysian or Non-Malaysian participation. The results are shown in Table 6.10 and are illustrated in the interaction graph of Figure 6.13.

Table 6.10 Contrasted percentage of number of steps completed across interaction interface and expertise

	Contrast Percentage Number of Steps Completed			
	Curry Paste	Cook Fish	Prepare Chicken	Cook Chicken
Curry Paste		n.s	$p < 0.05$	n.s

n.s = not significant

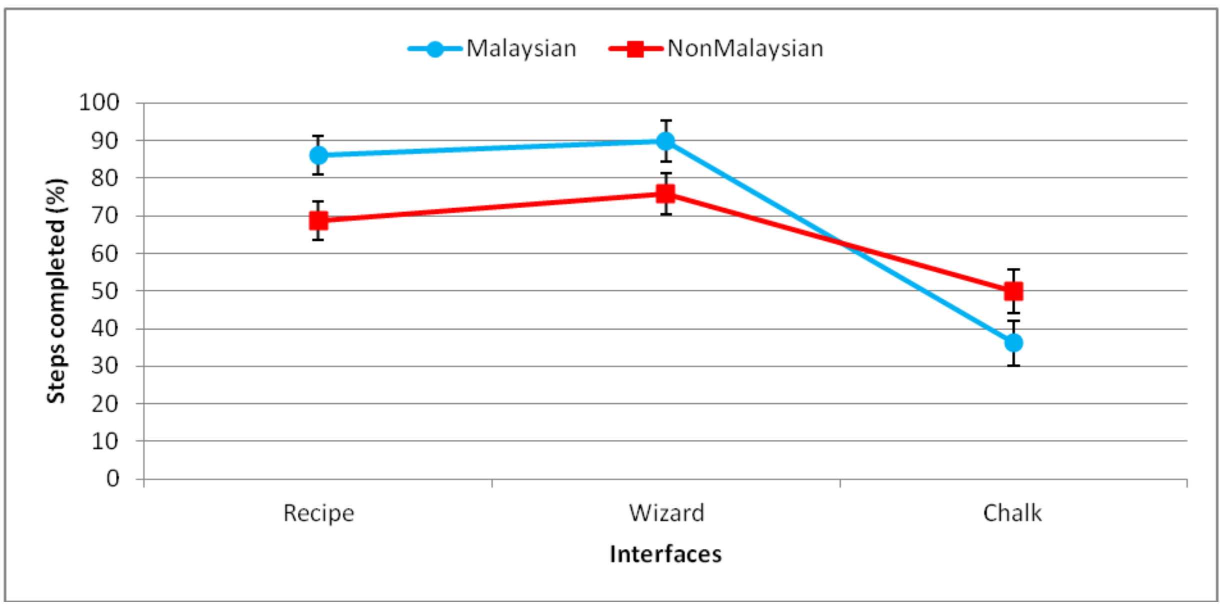


Figure 6.13 Percentage of steps completed in the interaction interface across Malaysian and Non-Malaysian

The results also show there was a significant interaction effect between interface interaction and cooking tasks [F (3.89, 70.16) = 3.592, p = 0.011] which indicates the percentage of steps completed in the interaction interfaces differed between cooking tasks. To break this interaction down, contrasts were performed comparing *recipeBook* and *smartChalk* to *ambient* across each cooking task to the *curryPaste* task. Results are shown in Table 6.12 and illustrated in Figure 6.14. Figure 6.14 shows that percentages of number of steps completed in all the cooking tasks through *smartChalk* were lower compared to *recipeBook* and *Ambient* conditions.

Table 6.11 Contrasted percentage of number of steps completed across interaction interface and cooking tasks

	Contrast Cooking Task x Interaction Interface							
	smartChalk vs. Ambient				recipeBook vs. Ambient			
	Curry Paste	Cook Fish	Prepare Chicken	Cook Chicken	Curry Paste	Cook Fish	Prepare Chicken	Cook Chicken
Curry Paste		n.s	n.s	n.s		n.s	n.s	p = 0.001
Cook Fish	n.s				n.s			
Prepare Chicken	n.s				n.s			
Cook Chicken	n.s				p = 0.001			

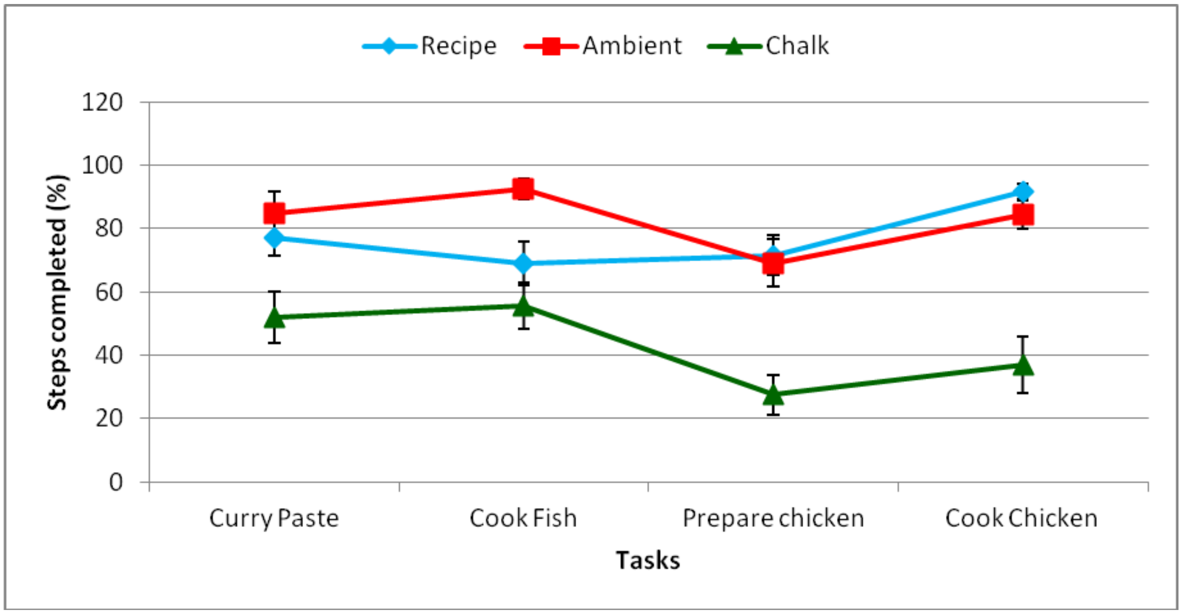


Figure 6.14 Percentage of steps completed in the cooking tasks across three different interactions

There was no interaction effect due to *task* and *participants* [F (1.97, 35.39) = 1.406, p = 0.258] or *interface*, *task* and *participant* [F (3.89, 70.16) = 0.682, p = 0.603].

Post-hoc, pairwise comparison, using a T-Test revealed no difference in percentage of steps completed between the *recipeBook* and *ambient* conditions for either the Malaysian or the Non-Malaysian participants. However, Malaysian participants completed significantly fewer steps using *smartChalk*, compared to *recipeBook*, or *ambient.* For Non-Malaysian participants, there was a significant difference between *smartChalk*, *ambient* condition and *recipeBook*. These results are shown in Table 6.12 and illustrated in Figures 6.15 and 6.16.

Table 6.12 T-Test percentage of steps among Malaysians and Non-Malaysians

	T-Test Percentage Number of Steps Completed		
	Malaysian		
	recipeBook	Ambient	smartChalk
recipebook		n.s	$p < 0.001$
Ambient	n.s		$p < 0.001$
smartChalk	$p < 0.001$	$p < 0.01$	
	Non-Malaysian		
	recipeBook	Ambient	smartChalk
recipebook		n.s	$p < 0.05$
Ambient	n.s		$p < 0.001$
smartChalk	$p < 0.05$	$p < 0.01$	

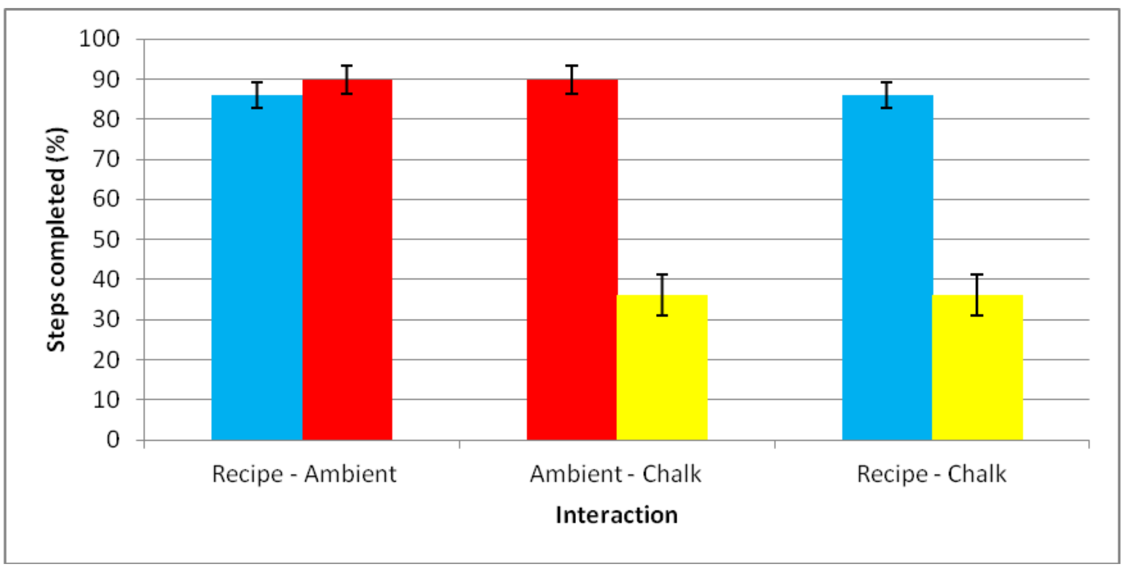


Figure 6.15 Percentage of steps completed for Malaysian participants

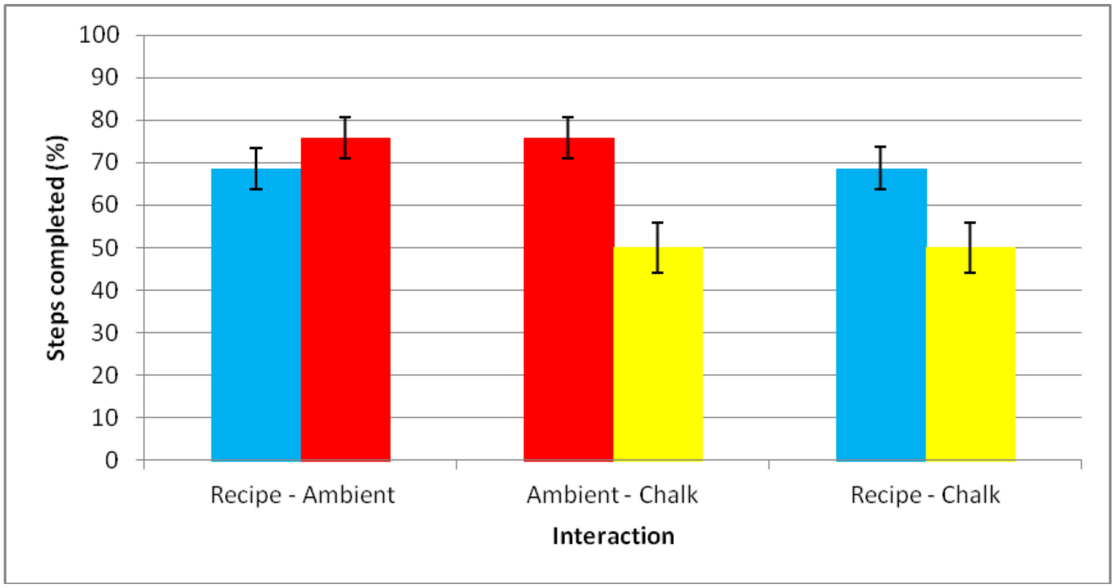


Figure 6.16 Percentage of steps completed for Non-Malaysian participants

Another T-Test was conducted to test the percentage of the number of steps completed without considering the differences in expertise. The results revealed significant differences in *recipeBook* and *ambient* conditions but no difference in the *smartChalk* condition. Table 6.13 and Figure 6.17 illustrate these T-Test results.

Table 6.13 T-Test on percentage of number of steps completed

	T-Test Number of Steps Completed
	Malaysian and Non-Malaysian
recipeBook	$p < 0.05$
Ambient	$p < 0.05$
smartChalk	n.s

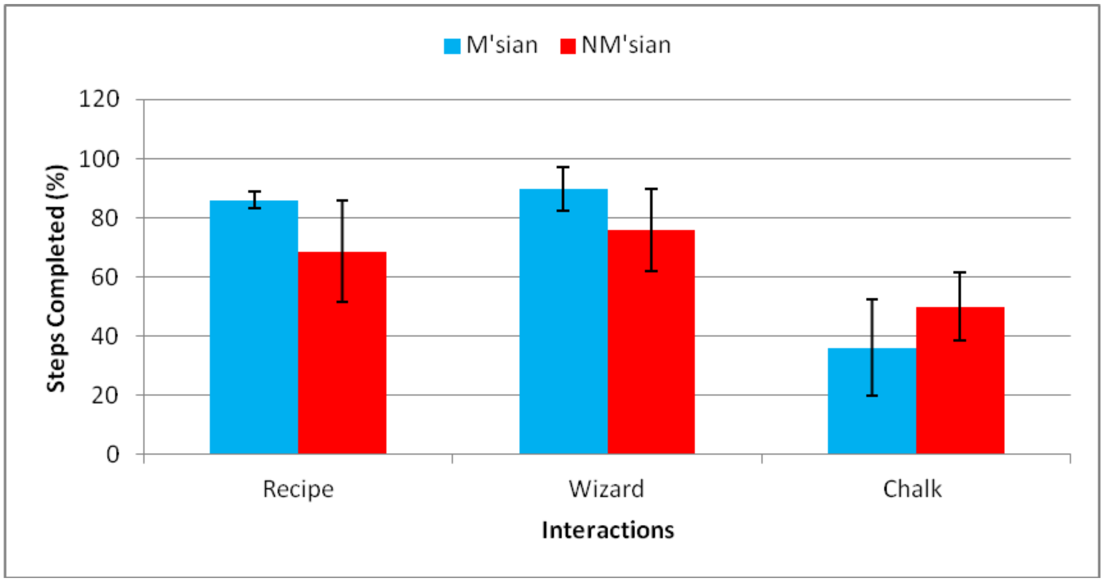


Figure 6.17 Percentage of steps completed for overall tasks in different interaction interfaces

Even though cooking times for non-Malaysians in *ambient* condition were not significantly different to those using *smartChalk*, the percentages of steps completed are higher in *ambient* conditions on all the cooking tasks. For Malaysian participants, both *recipeBook* and *ambient* conditions have a higher percentage of steps completed than in *smartChalk.*

6.3.3 Number of Errors

Errors in this study involved actions omitted (deliberate or not) by participants during the experimental tasks. Analysis and manual transcription was undertaken for all the cooking activities' videos. This analysis resulted in six different types of errors being identified for the experiments. These errors were shown in Table 6.14.

Table 6.14 Types of errors made by participants during cooking activities

Types	Errors	
I	Pointing to instructions	Ignore pointing the ingredients.
II	Pointing to ingredients	Ignore picking up the ingredients
III	Picking up only	Ignore adding the ingredients
IV	Steps omitted	Skips the step
V	Other actions	Various types of other errors
VI	Time's up	5 minutes up
VII	Pick up, add without pointing	Ignore using a smart chalk as pointing device

Type I: This error was when a participant would 'tap' or 'point' to the instruction but ignore the requirement to explore more about the ingredients or steps to do.

Type II: This error occurred when a participant would 'point' to the ingredient with the chalk, but ignore the need to pick up the ingredients.

Type III: This error was when a participant would pick up the ingredient but not 'add' the ingredient to the necessary utensils.

Type IV: This error was when a participant failed to perform the step.

Type V: Other different types of errors.

Type VI: Participant did not complete the task within 5 minutes.

Type VII: Participant ignored using the chalk as the pointing device, but picks and adds the ingredients.

Percentages of errors in the cooking tasks for each interaction interface across Malaysian and Non-Malaysian participants are shown in Table 6.16. Malaysian and Non-Malaysian participants made errors mostly in *smartChalk* interface [curryPaste (M'sian = 33%, NM'sian = 48%), cookFish (M'sian = 55%, NM'sia = 37%), prepareChicken (M'sia = 98%, NM'sia = 65%) and in cookChicken (M'sia = 76%, NM'sia = 51%)]. While this can be explained simply by the fact that this condition has unique errors associated with it (i.e., Type II and Type VII) it also suggests that the use of the *smartChalk* caused problems for these tasks.

Table 6.15 also shows that both Malaysian and Non-Malaysian participants made Type IV errors in Curry Paste with respectively 30% and 60%, while in Cookfish, Malaysian participants made 31% of Type VII error and 24% Type II error, for Non-Malaysians. Malaysian participants also made the same Type VII error in Prepare Chicken with 42% and 57% in Cook Chicken however non-Malaysians made Type IV error in Prepare Chicken (68%) and Cook Chicken (33%). Malaysian and Non-Malaysian participants made errors mostly in the *smartChalk* interface.

Table 6.15 Percentages of errors made by Malaysian and Non-Malaysian in all the cooking tasks with different interaction interfaces

Malaysian	**Curry Paste (5)**			**Cook Fish (10)**			**Prepare Chicken (6)**			**Cook Chicken (7)**		
Interaction	Recipe	Wizard	Chalk	Recipe	Wizard	Chalk	Recipe	Wizard	Chalk	Recipe	Wizard	Chalk
Types of Errors												
I									8			6
II			10			11			12			
III		4		10				3			14	
IV	14	6	10	7		13	7	10	23	10		13
V								3				
VI			5				8		13			
VII			8			31			42			57
Total Errors (%)	**14**	**10**	**33**	**17**	**0**	**55**	**15**	**17**	**98**	**10**	**14**	**76**
Non-Malaysian												
I			6			3	7	3	10			14
II			18	6	6	12	3	5	17			3
III							7	5				
IV	26	20	20	5	5	6	13	23	32	9	17	7
V							10	8	2			
VI	8		4		3	16	3		5			
VII												27
Total Errors (%)	**34**	**20**	**48**	**11**	**14**	**37**	**43**	**45**	**65**	**9**	**17**	**51**

Chi-Square tests on errors were performed between Malaysian and Non-Malaysian participants across each interaction in the cooking task. The results show that there were significant differences in the number of errors made by Malaysians and Non-Malaysians in the *recipeBook* for *curryPaste* and *prepareChicken* tasks. Meanwhile, in the *ambient* condition, there were significant differences in the number of errors made between Malaysians and Non-Malaysians for *cookFish* and *prepareChicken* task and significant differences in the number of errors made in the *smartChalk* for *cookFish* and *cookChicken*. Results are shown in Table 6.16.

Table 6.16 Results of Chi-Square test for total number of errors between Malaysian and Non-Malaysian in the cooking tasks for different interaction interfaces

Task	Recipe	Ambient	Chalk
Curry Paste	x^2 (1) = 5.616*	n.s	n.s
Cook Fish	n.s	x^2 (1) = 20.463**	x^2 (1) = 6.559*
Prepare Chicken	x^2 (1) = 9.674*	x^2 (1) = 11.619**	n.s
Cook Chicken	n.s	n.s	x^2 (1) = 9.044*

*(*p < 0.05, **p < 0.001, n.s = not significant)*

Chi-Square tests on errors were performed for Malaysian and non-Malaysian participants and show that, for each task, there were significant differences in the numbers of errors made with the different interfaces. These results are shown in Table 6.17.

Table 6.17 Results of Chi-Square test for the total number of errors made by Malaysian and Non-Malaysian in cooking tasks.

Task	Malaysian	Non-Malaysian
Curry Paste	$x^2(2) = 21.0^{**}$	$x^2(2) = 8.9^{*}$
Cook fish	$x^2(2) = 25.26^{**}$	$x^2(2) = 23.61^{**}$
Prepare Chicken	$x^2(2) = 72.8^{**}$	$x^2(2) = 8.5^{*}$
Cook Chicken	$x^2(2) = 86.8^{**}$	$x^2(2) = 37.4^{**}$

(*$p < 0.05$, **$p < 0.001$, n.s = not significant)*

Results from the Chi-Square test show that the numbers of steps and ingredients in particular cooking tasks affect the performance of activities in the user interface. Prepare *curryPaste* and *prepareChicken* show that non-Malaysian participants made the most errors while performing the cooking tasks in the *recipeBook* compared to Malaysian participants which suggests that the higher number of unknown ingredients may contribute to the mistakes made during the cooking activities. In the *cookFish task*, Malaysian participants did not make any mistakes when performing the cooking activities in the *ambient* condition but made a significant number of errors in the *smartChalk* condition. Based on these results, Malaysians prefer to perform cooking activities in the *ambient* condition despite having the advantage of knowing the recipes and ingredients in the *recipeBook* condition. Although Non-Malaysian participants made fewer errors in the *smartChalk* compared to Malaysian participants, findings from Chi-Square analysis show that the number of errors in the *ambient* condition is less than in *recipeBook* and *smartChalk* conditions. This suggests that Non-Malaysian participants prefer an *ambient* condition when it involves simple recipes i.e. fewer ingredients.

6.4 Discussion

The user trials of simulated cooking activities demonstrate that a number of important factors need to be considered in developing Ubiquitous Computing for the kitchen environment in the future.

The results of this study suggest that the indirect form of interaction, using *smartChalk*, makes it more likely that users will make more errors while cooking. This suggests that not only does the indirect form of interaction produce a *physical* distraction in task performance (requiring participants to stop what they are doing in order to use the interaction device) but it also, and more interestingly, produces a *cognitive* distraction in which users lose their place, forget what to do next or become distracted from their primary tasks. This is due to the fact that 'indirect' interaction causes users to perform two different tasks; 'cooking' and 'pointing using chalk' which might require additional attention and might distract from their main performance. A review of video analyses suggests that some of the participants attempted to cope with this demand by simply ignoring the use of the *smartChalk*, preferring instead to rely on their knowledge of the task or to guess which step to perform next, and they had to be reminded by the experimenter to perform the appropriate actions.

Overall, ambient displays which provide a standard and natural cooking interface give more advantages in terms of cooking performance and accessing digital information. This example of interaction as shown in *ambient* proves that users can be supported by providing information based on the actions users perform. Ambient displays have given users certainty in cooking activities compared to *recipeBook* with which the user might be confused between 'self' and 'expert' especially for those who have expertise in particular recipes.

While the experiment showed significant differences in terms of 'expertise' (as one might expect) it is interesting to observe the relative differences in effects of the interfaces on task performance: notably, the indirect interface led to greater disruption to the 'expert' (Malaysian) participants than to the non-expert participants. Presumably this is due to the disruption of indicating ingredients by pointing for people who know how to perform the task. Even more interestingly, the 'ambient' interface seemed to enhance performance of the Malaysian participants. Presumably this was due to the fact that there was little or no interruption to task performance and the projected information could confirm the choice of ingredient. This confirmation was of use to the Malaysian participants because the labels for the experiment used the English names for ingredients and some of these were unfamiliar to them (thus, the projection was beneficial).

6.5 Conclusions

This chapter reports results from a study using a simulated cooking task employing three types of user interface; *recipeBook*, *ambient* and *smartChalk*. As well as comparing user interfaces, the study compares two levels of expertise in cooking specific Malaysian recipes.

The main conclusion from this study is that direct interaction such as ambient interaction supports and provides a ‘natural’ form of interaction in the digital environment but indirect interaction causes a delay in the cooking activities as two different actions are required to be performed simultaneously: pointing and cooking. That the indirect interaction interrupted primary task performance, which was disruptive, raises the next question to be addressed in this thesis: How do people cope with ambient cueing when they have to deal to interruptions?

CHAPTER 7
The Impact of System Malfunction on Human Performance in the Digital Kitchen

The previous chapter presented three means of supporting cooking activity in the digital kitchen. The results showed that ambient cueing (in which projected information was presented in response to a user's cooking actions) tended to lead to a performance for both the experienced and inexperienced participants in that study that was superior to both a paper-based recipe book and with a form of indirect interaction using projected media. The study also showed that the indirect form of interaction (in which the cooking task was interrupted in order to select information) led to problems with both physical and cognitive activities. Interruptions could cause problems for users of projected displays. In this chapter, the question is whether interruptions can be helped or exacerbated by projected displays. A smart environment is simulated where a projected display is used to support cooking activities in a kitchen of the future. From the point of view of human factors, a critical issue is how users of such a system might cope with its malfunction, either because the system is unable to recognise a person's activity or because it has confused two recipes.

What is apparent from the brief review in Chapter 2 was that the concept of a kitchen environment which can respond to its users and provide advice and guidance on cooking tasks is becoming increasingly interesting to the pervasive and ubiquitous computing domains. What is equally apparent is that there remains a dearth of studies of how people will interact with such environments (and whether such environments are actually desirable or beneficial). For this chapter, our interests lie in the manner in which people cope with malfunctions. In related work, interruptions have been shown to adversely affect cooking tasks (Tran and Mynatt, 2002).

In the user trial of the 'ambient stove' (reported in Chapter 5) it was shown that the non-compatible arrangements led to significant reductions in performance. In this chapter, the issue of 'compatibility' is considered in terms of the potential conflict between the user's expectations and the information provided. By taking advantage of the flexibility offered by the *Wizard of Oz* approach, a study explored the performance of cooking activities when system malfunction could result in distraction during cooking tasks in the digital kitchen.

The next section will explain the motivation of the experiment and define the experiment hypothesis. Experimental step-up, participants and procedure will be described in Section 7.2 while in Section 7.3 the recorded measurement and results will be reported. Section 7.4 will summarise the experiment's findings, discussion on the implementation and the future works of this experiment.

7.1 Design and Hypotheses

In this study, performance under three conditions is compared. As with the 'ambient' condition in the previous chapter, the 'real' cooking activity is prompted by projected cues. The cooking task chosen for this study was two Malaysian recipes with a different number of steps, different types of ingredients and different cooking skills.

As with the previous chapter, a functional prototype was designed to 'assist' users performing a cooking activity in an augmented kitchen environment, projected on top of the table by an LCD projector. Before each task, the ingredients are placed in small, ceramic containers and arranged on the table. This layout provides a convenient structure for the projections so all participants face exactly the same arrangement with all ingredients and utensils positioned in the same places prior to the start of the trials. Figure 7.1 shows the surface divided into four sections: 'workspace' (where the user performs the cooking tasks), 'instructions' (containing steps to follow and which ingredients and utensils to use), 'ingredients' (containing 24 ingredients) and 'utensils' (where the equipment and tools are placed).

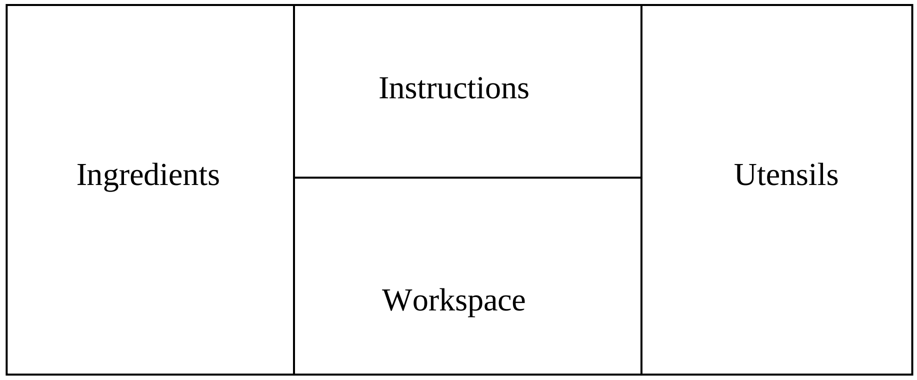


Figure 7.1 The Layout of the surface for this experiment

By tapping the projected icons or by placing their hand on or next to an ingredient or utensil, a coloured disc is projected on top of the object. This disc indicates whether the ingredient is right, or wrong, for that step of the recipe (a light green disc for right ingredient and a dark red disc when the ingredient is wrong). If the correct ingredient is selected, the name of the ingredient will change to green text at the same time. For the purposes of this trial, the action of the participant is monitored by the experimenter who cues the appropriate information (thus, following a standard 'Wizard of Oz' approach to prototyping).

This study compares user performance under three experimental conditions in an ambient kitchen. These are a control condition with no system malfunction, a condition with simple system malfunctions and a condition with more complex system malfunctions. The simple system malfunction involved the projected display highlighting an ingredient with incorrect information (red circle) when it was the correct ingredient. This could, for example, replicate a situation in which the cueing is to a location rather than to a specific ingredient (and the ingredient is in the 'wrong' place as far as the cueing is concerned). On the other hand, the complex system malfunction was a condition in which an additional step was shown to the participants. This could represent a situation where the automatic prompting confuses one recipe with another. The purpose of this experiment is to explore how the performance of a cooking task, performed by experts, is affected when the system goes wrong.

The cooking task chosen for this study were two Malaysian recipes: Red Spicy Chicken and Fish Grill stuffed with Coconut Chilli Paste. These recipes represent different levels of cooking activity (with a different number of steps, different types of ingredients and different cooking skills). The Fish Grill task has fewer ingredients but a higher level of cooking skills, while Red Spicy Chicken has a lower level of cooking skills but a higher number of ingredients and steps to perform. Each cooking task was broken down into three (3) subtasks as shown in Table 7.1, which also shows number of steps, ingredients, tools and cooking actions.

Table 7.1 Relative 'complexity' of cooking subtasks

	Prepare Curry paste	**Cook Fish**	**Prepare Chicken**	**Cook Chicken**
Steps	5	10	6	7
Ingredients	10	14	12	3
Tools	2	3	4	3
Actions	3	5	4	6

Two different forms of help were available to participants after the distraction: participants could ask the system to "show" the whole list of steps by tapping the letter "S", or they could ask for an “inventory” by tapping the letter “I”. This inventory will list the ingredients that should been used from the start of the task.

Each subtask was then tested with different types of system malfunction mode: (control) *no system malfunction; simple system malfunction,* and *complex system malfunction.*

The study in Chapter 6 suggested that participants could confuse ingredients that have similar characteristics such as physical appearance, colour or name. In order to avoid participants being aware of changes made, only a selection of these ingredients were wrongly highlighted in each of these conditions (and the selection varied between participants). Table 7.2 shows the ingredient changes in the *simple system malfunction* and Figure 7.2 illustrates the sample of simple system malfunction.

Table 7.2 Changes of highlighted ingredients in the Simple System Malfunction

Correct Ingredients	Incorrect Ingredients
Shallots	Red Onion
Ginger	Galangal
Turmeric Powder	Curry Powder
Salt	Sugar
Cinnamon	Cardamon
Cooking Oil	Fish Sauce
Cloves	Halba
Honey	Sesame Oil
Sesame Seeds	Raisins

Figure 7.2 Illustration of simple system malfunction. Participant picked up the right ingredient (shallot); but the system highlighted that the ingredient was wrong (by using a red light in the space where the ingredient was picked up from).

Complex system malfunction was a condition in which an additional step (from a different recipe) was presented to the participants. This could represent a situation where the automatic prompting confuses one recipe with another. This step was defined as a *distraction step*, not related at all to the primary cooking task which is spuriously introduced. The *complex system malfunction* scenario was a combination of distraction step and simple distraction (as discussed above). The action or ingredient involved in the distraction step might be similar to the previous step (primary step). Figure 7.3 illustrates the complex system malfunction.

Figure 7.3 Illustration of complex system malfunction which shows the *distraction step* (in the text list of actions to be performed)

On the basis of this description, 18 Cooking System Malfunctions were created based on the combination of subtasks and type of system malfunction.

User performance was defined as successfully performing the task and was measured by the time taken to complete the task, the number of steps completed and errors made. Therefore, the following hypotheses were made.

i. **Hypothesis 1 (H1):** Interaction with system malfunction requires more time to complete the task than with no system malfunction within the same cooking scenarios.
ii. **Hypothesis 2 (H2):** A cooking task with a higher level of cooking activity (see above) at the time of system malfunction will demonstrate a higher error rate than a cooking task with a lower level of cooking activity.

7.2 Participants and Procedures

The three scenarios previously discussed (no system malfunction, simple system malfunction and complex system malfunction) were applied to three subtasks of each main cooking task. This resulted in 9 (3x3) different cooking system malfunctions for each main cooking task; Red Spicy Chicken and Grill Fish.

The cooking system malfunctions were assigned randomly throughout the cooking tasks in order to reduce expectations. Randomisation was accomplished by ‘shuffling’ the cooking system malfunction at the beginning, middle or end of the cooking task. In order to ensure that participants did not recall previous cooking system malfunctions there was a gap of at least 15 minutes between each system malfunction. The completed experiment for each participant, including debrief, lasted about an hour.

12 native Malaysian participants were recruited for this study, in which four (N=4) different individuals participated in each cooking system malfunction. All the participants were aged between 22 and 35 years. Three participants were male and nine were female. All the participants were familiar with the recipes and had at least three years of cooking experience. These experiences included a participant’s familiarity to cook basic Malay dish such as making a *sambal* (prepare, boil, blend and stir dried chillies) or were familiar with Malay’s most common ingredients such as *lengkuas* (galangal), *jintan manis* (fennel), or ketumbar (*coriander seeds).*This sample size is sufficient for detecting large effects in user performance with significant power < 0.5 with between subjects using two-way ANOVA repeated measures design.

The experiment set-up was similar to the previous experiment (see Chapter 6) where an ambient interface was projected on top of the table which acted as an augmented kitchen counter. Due to health and safety issues within the building where the experiment was running, a cooking activity would not involve any real cooking; however, participants were asked to perform the action to their best ability and to describe it: for example, "Stir and mix the ingredients well" meant that what participants can do was to take a tablespoon or spatula and make a 'stir' action by stirring the ingredients clockwise repeatedly with the tablespoon, while for "fry the ingredients" participants put the ingredients into the frying pan and stirred them.

Each participant was given a standard instruction at the beginning of the experiment. The instructions were as follows.

i. Participants are required to complete each cooking task by following the steps and instructions given.
ii. There is no time limit in this experiment; participants are allowed to take as long as they want until they have completed the task.
iii. Participants are required to 'think-aloud' while performing the cooking task.

Participants were informed that during the cooking activity, a system malfunction could be introduced, but the details of how, when and where it would occur was not given. The purpose was to detect whether participants could recognise a system malfunction during the task.. Once participants completed reading the instructions, a small demonstration was made by the experimenter on how to use and interact with the ambient display. Participants were then given one or two minutes to familiarise themselves with the display and the required interaction.

During the experiment, all the cooking actions were recorded using a digital camera and the videos were fully transcribed at the end of the experiment.

7.3 Results

A series of two-way ANOVA was conducted on the data to examine the times to complete the task, the number of steps completed and the number of errors made for each recipe.

7.3.1 Cooking Times

Cooking times were collected in two different forms; ***total times (TT)*** and ***time on system malfunction (TOSM).*** These times were defined as below.

- **Total Times (TT)**: The total of time spent to complete the cooking task. The time spent during the system malfunction and the primary cooking is included in this measurement.
- **Time on system malfunction (TOSM)**: The amount of time spent during the ambient failing (or system malfunction) event.

Two-way ANOVA was used to measure the total times with two independent variables in each recipe: ***task*** (three cooking tasks for each recipe) and ***system malfunction*** (no malfunction, simple system malfunction and complex system malfunction). These two variables completely cross over producing nine experimental conditions in each recipe with four independent participants.

7.3.1.1 Red Spicy Chicken

A two-way ANOVA was conducted that examined the effect of different types of system malfunction and cooking task (redPaste, prepareChicken and cookChicken) on cooking times.

Results showed there was homogeneity of variance between groups as assessed by Levene's test for equality of variances. There was a significant main effect of types of system malfunction on cooking times [F (2, 27) = 4.370, p = 0.02]. Tukey HSD *post-hoc* test revealed that cooking times were significantly faster in the *no system malfunction* than in the *complex system malfunction* (p = 0.03) but there were no differences in cooking times between *simple* and *no system malfunction* (p = 0.08) or between *simple* and *complex* (p = 0.85). These results are illustrated in Figure 7.4.

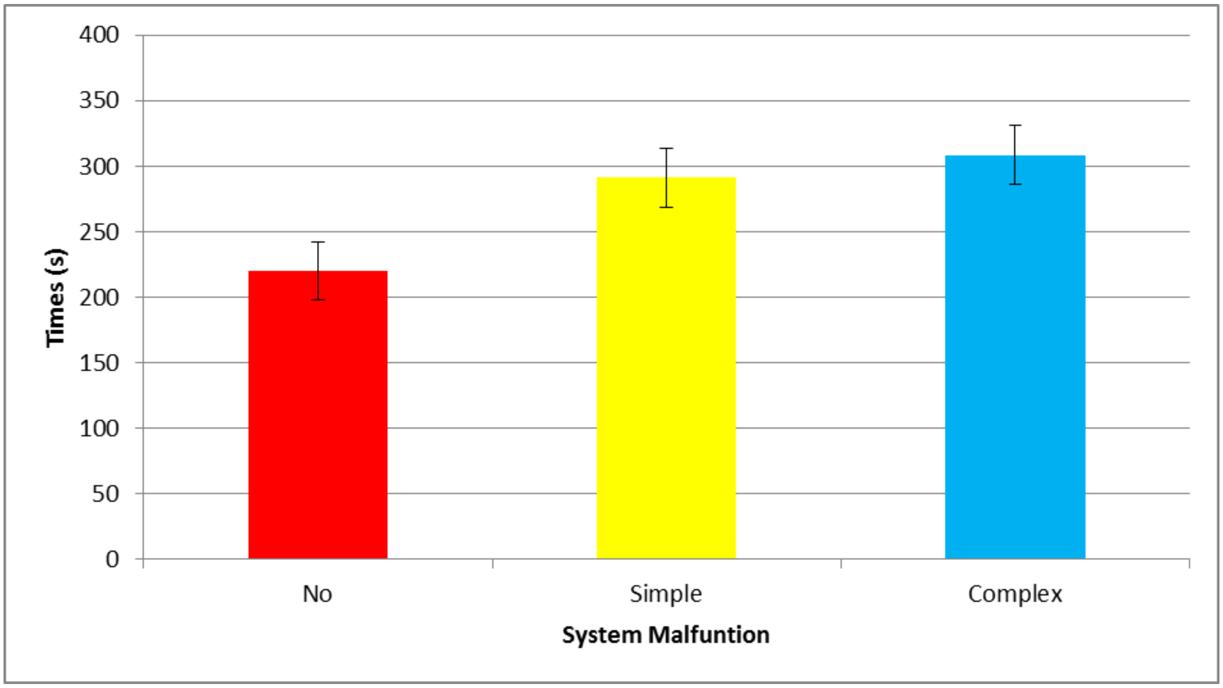


Figure 7.4 Average cooking times in three different types of system malfunction in *Red Spicy Chicken* cooking activity

Results also showed there was a significant main effect of cooking task on the cooking times [F (2, 27) = 11.009, p < 0.001]. Tukey HSD *post hoc* test revealed that cooking times were significantly faster in the *prepareChicken* than *cookChicken* (p = 0.001) but no significance with *redPaste* (p = 0.81). A Post hoc test also revealed that cooking times were significantly slower in the *cookChicken* than *redPaste* (p = 0.003). These results are illustrated in Figure 7.5.

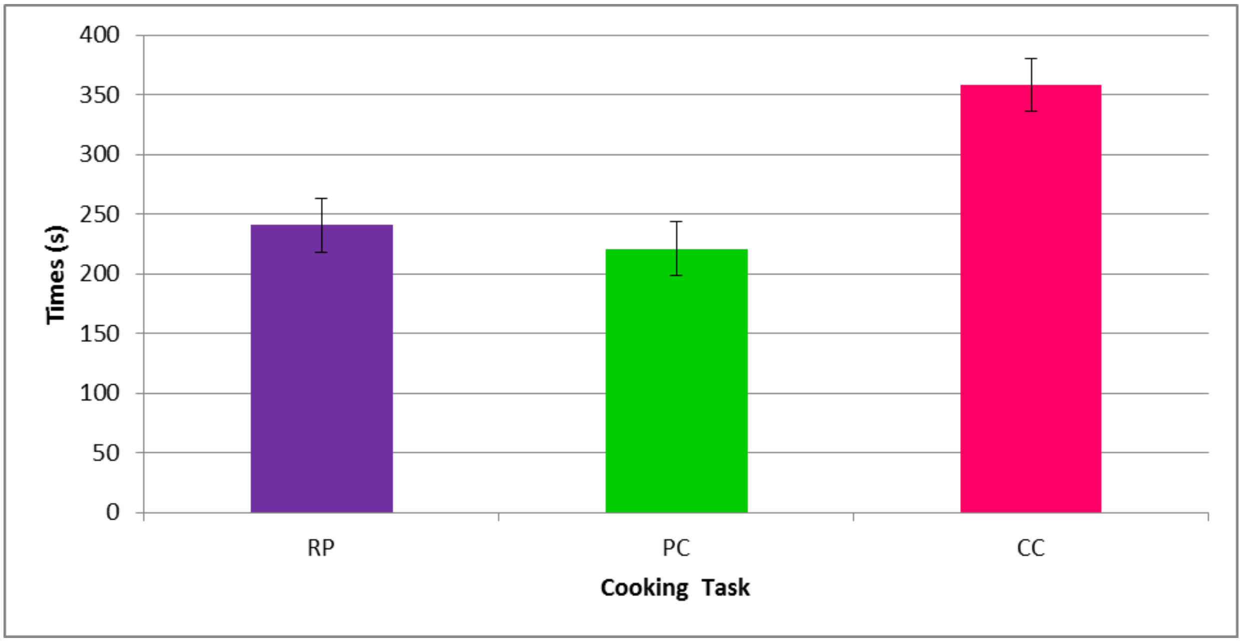


Figure 7.5 Average cooking times in different cooking subtasks in *Red Spicy Chicken.*

There was a non-significant interaction between the types of system malfunction and cooking tasks on the cooking times [F (4, 27) = 1.500, p = 0.23].

7.3.1.2 Fish Grill

A two-way ANOVA was conducted that examined the effect of different types of system malfunction and cooking subtask (chilliesPaste, prepareFish and cookFish) on cooking times. Results showed there was homogeneity of variance between groups as assessed by Levene's equality of variances.

There was a significant main effect of types of system malfunction on cooking times [F (2, 27) = 7.110, p = 0.04]. Tukey HSD *post hoc* test revealed that cooking times on the *no system malfunction* were faster than *complex system malfunction* (p = 0.05); however no significant effect of cooking times were found between the *simple* and *complex* system malfunctions (p = 0.1) or between *simple* and *no* system malfunction (p = 0.95). Results also showed no significant effect of cooking times between *no* to *simple* system malfunction (p = 0.95). Figure 7.6 illustrates these results.

There was a significant main effect of cooking task on the cooking times [F (2, 27) = 7.110, p = 0.003]. Tukey HSD *post hoc* test revealed that cooking times of *prepared fish* were significantly faster than *curry paste* (p = 0.006) and *cooking fish* (p = 0.01). The cooking times of *curry paste* were not significantly different from *cooking fish* (p = 0.97). These results are illustrated in Figure 7.7. There were no significant interaction effects between types of system malfunction and cooking tasks.

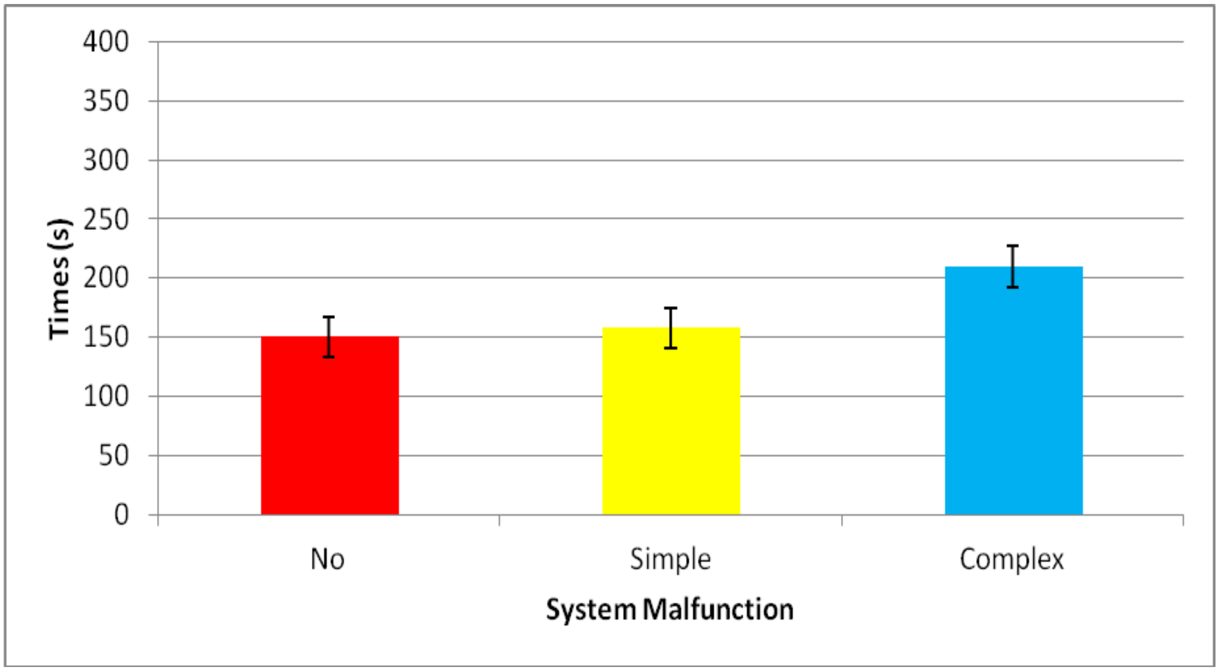


Figure 7.6 Average cooking times in three different types of system malfunction of *Fish Grill* cooking activity

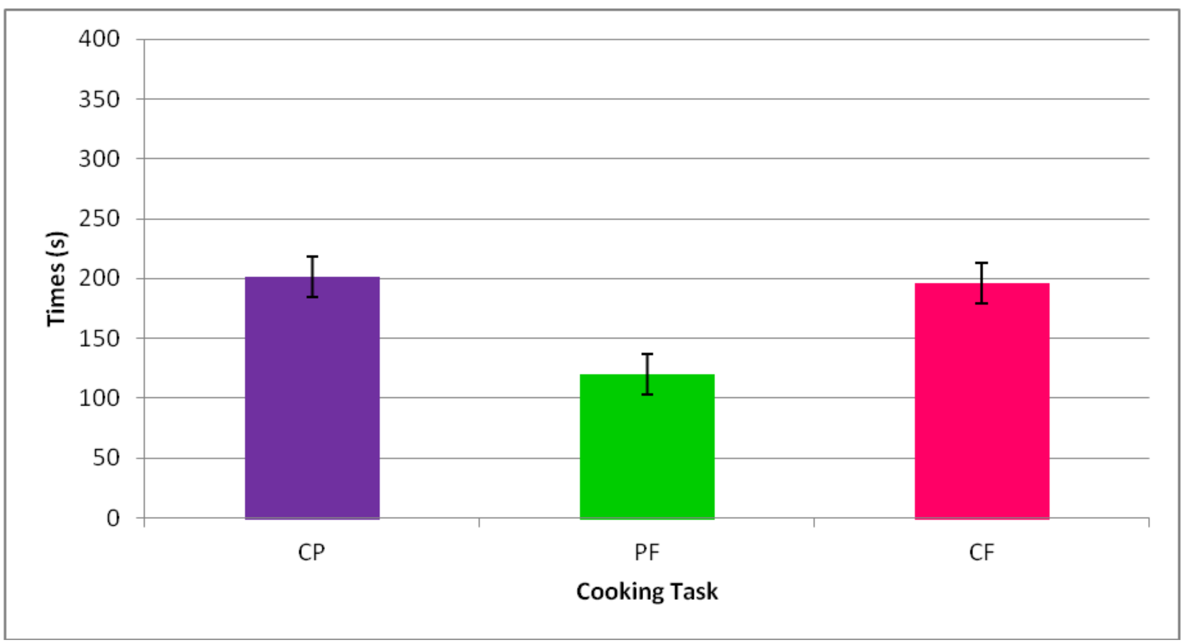


Figure 7.7 Average cooking times of different cooking tasks of *Fish Grill*

7.3.1.3 Summary of Cooking Times' Results

The present study measured the performance of cooking activities with Malaysian participants (who were all familiar with the recipes and ingredients) when system malfunctions occurred. It was found that complex system malfunction slows performance significantly more than the simple system malfunction or no system malfunction. This suggests that complex system malfunction resulted in participants getting confused by the 'extra' step involving the other recipes which have similar ingredients and which have been used before. Reviews from the video analysis show that one participant complained about the cooking task: "*I thought I had already used this ingredient, why do I need to use it again?"* but still continued to follow the instruction given. Another participant skipped the 'extra' step after realizing it has confused her: "*This is not right, something weird here, I want to skip this step because I have taken this ingredient, why do I need to use twice?"*

7.3.2 Number of Steps Completed

The number of steps varied between the cooking tasks: *redPaste* (5), *prepareChicken* (6), *cookChicken* (9), *chilliesPaste* (6), *prepareFish* (4), *cookFish* (6). Through video analysis, steps completed were defined as follows:

- No missing ingredients in each step
- No missing cooking actions, i.e. missing 'add', 'peel', 'blending'

- Did not use wrong ingredients.

If one of the above elements occurred in a step, that step was counted as ‘incomplete’.

Since there was a different number of steps in each cooking task, one-way ANOVA was used to measure the number of steps completed with two independent variables in each recipe: ***task*** (three cooking tasks for each recipe) and ***system malfunction*** (no system malfunction, simple system malfunction, and complex system malfunction). These two variables completely cross over producing nine experimental conditions in each recipe with four independent participants.

7.3.2.1 Red Spicy Chicken

A one-way ANOVA was conducted that examined the effect of different types of system malfunctions and cooking subtasks (redPaste, prepareChicken and cookChicken) on the number of steps completed in this recipe.

Results of Levene’s Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on steps completed in the *redPaste* task. There was no main effect of system malfunction as determined by one-way ANOVA [$F(2, 9) = 2.053$, $p = 0.184$]. A Tukey *post hoc* test revealed that the steps required to complete the *redPaste* task were not significantly different between *no* to *simple* system malfunction ($p = 0.18$) and to *complex system malfunction* ($p = 0.88$). There was no significant difference in the number of steps completed between *simple* to *complex* system malfunction ($p = 0.35$).

Results of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the steps completed in the *preparechicken* task. There was a statistically significant difference between types of system malfunction as determined by one-way ANOVA [F (2, 9) = 6.617, p = 0.02]. A Tukey *post hoc* test revealed that the number of steps completed in the *prepareChicken* task was statistically lower and more significant in the *simple system malfunction* compared to *no system malfunction* (p = 0.02). There were no statistically significant differences between the *simple* and *complex* system malfunction (p = 0.17) and *complex* and *no* system malfunction (p = 0.34).

The results of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the steps completed in the *cookChicken* task. There was a statistically significant difference between the types of system malfunction as determined by one-way ANOVA [F (2, 9) = 14.778, p = 0.001]. A Tukey *post hoc* test revealed that the number of steps completed in the *cookChicken* task was statistically significantly lower after completing the cooking task in *simple* (p = 0.004) and *complex* (p = 0.002) system malfunction compared to the *no system malfunction* (M = 8, SD = 0.82). There were no statistically significant differences between the *simple* and *complex* system malfunction (p = 0.91). Figure 7.8 illustrates these results.

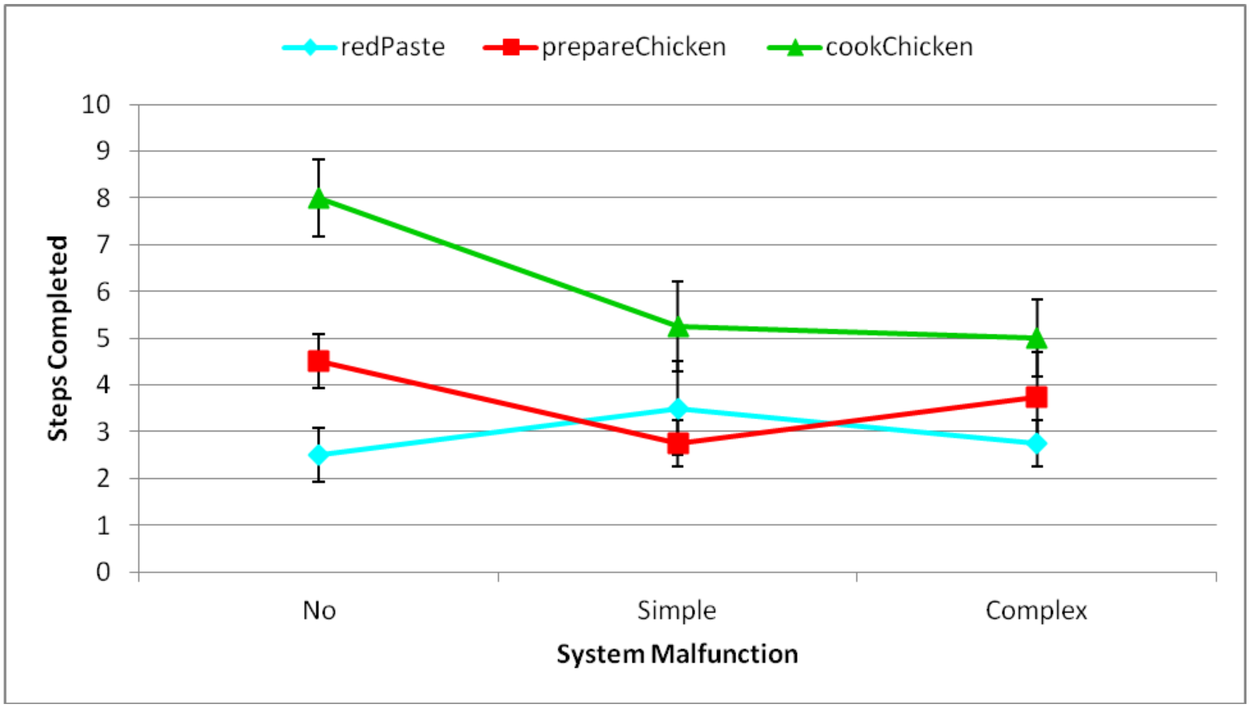


Figure 7.8 Number of steps completed in cooking task with three different system malfunctions in the *Red Spicy Chicken*

7.3.2.2 Fish Grill

A one-way ANOVA was conducted that examined the effect of different types of system malfunctions and cooking subtasks (chilliesPaste, prepareFish and cookFish) on the number of steps completed in the Fish Grill recipe. Figure 7.11 illustrates the results of number of steps completed in the Fish Grill recipe.

Results of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the steps completed in the *chilliesPaste* task. There was no statistically significant difference between types of system malfunction as determined by one-way ANOVA [F (2, 9) = 0.211, p = 0.814). A Tukey *post* hoc test revealed that the steps required to complete the *chilliesPaste* task were not significantly different between *no* to *simple* system malfunction. ($p = 1$) and to *complex* system malfunction ($p = 0.84$). There was also no significant effect on the number of steps completed between *simple* to *complex* system malfunction ($p = 0.84$).

Results of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the steps completed in the *prepareFish* task. There was a statistically significant difference between types of system malfunction as determined by one-way ANOVA [$F(2, 9) = 5.5700$, $p = 0.03$]. A Tukey *post hoc* test revealed that the number of steps completed in the *prepareFish* task was statistically lower in the *complex* system malfunction compared to the *no system malfunction* ($p = 0.02$). There were no statistically significant differences between the *simple* to *no* ($p = 0.41$) and to *complex system malfunction* ($p = 0.17$).

The result of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the steps completed in the *cookFish* task. There was no statistically significant difference between types of system malfunction as determined by one-way ANOVA [$F(2, 9) = 0.103$, $p = 0.903$]. A Tukey *post hoc* test revealed that the number of steps completed in the *cookFish* task was statistically not significant when comparing *no system malfunction* to *simple* and *complex* (both ps = 0.97) and *simple* to *complex* ($p = 0.94$). The results of these one-way ANOVA are illustrated in Figure 7.9.

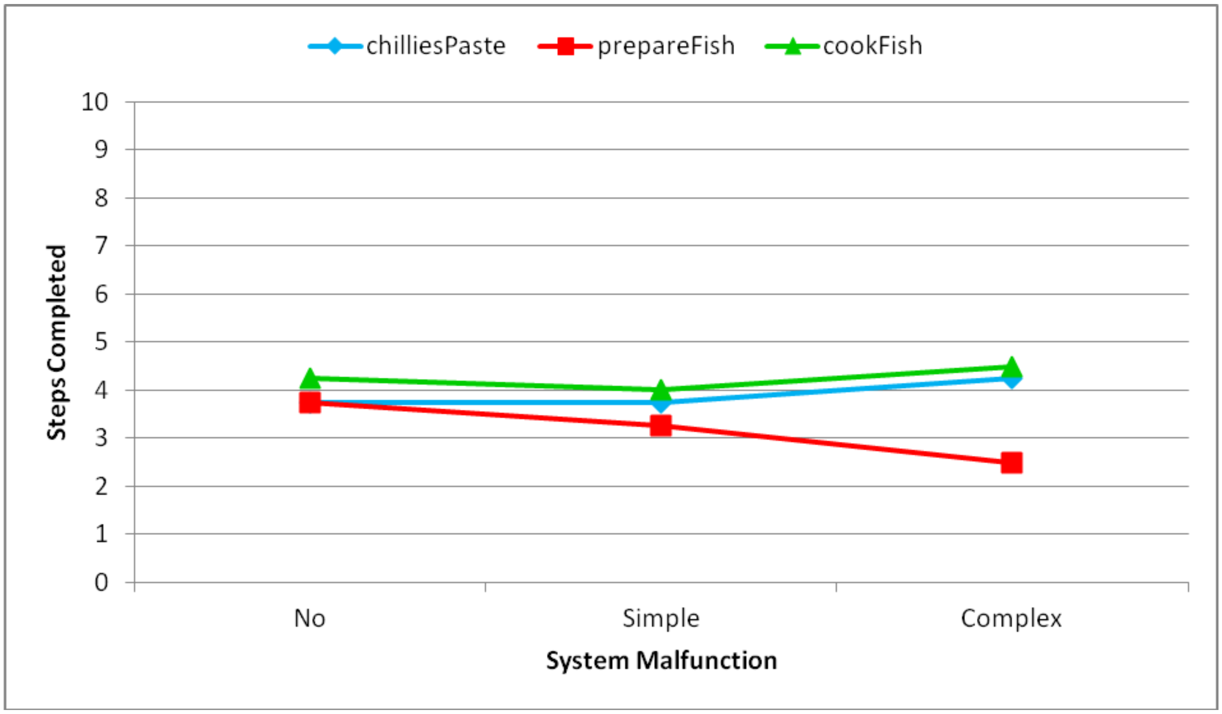


Figure 7.9 Number of steps completed in cooking task in the *Fish Grill* with three types of system malfunction

7.3.2.3 Summary of Number of Steps Completed

In terms of the number of steps completed, the results showed that the *complex system malfunction* resulted in fewer steps being completed than in the other conditions. This suggests that during the cooking activities in the *complex system malfunction, most* of the participants could not differentiate between the steps of the primary cooking task and the 'other' cooking task. This might suggest that users have confidence that the system gives *true* information and is guiding them to the accurate completion of the cooking tasks. One of the participants questioned the distraction step. "*This looks strange, errmm (re-read the ingredients and instruction) well... just follow the system, this is what the system wants me to do.*" Therefore, participants ended up confusing the cooking task in the primary recipe with others.

7.3.3 Number of Errors

As the number of steps varied between the cooking tasks, the probability of errors happening was higher as the number of steps was higher. Therefore one-way ANOVA was used to measure the number of errors occurring with two independent variables in each recipe: **task** (three cooking tasks for each recipe) and **system malfunction** (no system malfunction, simple system malfunction and complex system malfunction). These two variables completely cross over producing nine experimental conditions in each recipe with four independent participants. Through video analysis, errors were defined as follows:

- Used the wrong ingredients
- Did not perform cooking action i.e. ‘add’, ‘peel’, ‘blending’
- Missing any ingredients(s)
- Steps omitted.

7.3.3.1 Red Spicy Chicken

One-way ANOVA was conducted that examined the effect of different types of system malfunction and cooking tasks (redPaste, preparechicken and cookChicken) on a number of errors occurring in the Red Spicy Chicken recipe.

Results of Levene’s Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the number of errors occurring in the *redPaste* task. There was no statistically significant difference between types of system malfunction as determined by one-way ANOVA [$F(2, 9) = 0.392$, $p = 0.69$]. A Tukey *post hoc* test revealed that the number of errors in the *redPaste* task was not significantly different between *no* to *simple* system malfunction (p = 0.66) and to *complex* system malfunction (p = 0.93). There was also no significant difference between *simple* to *complex* system malfunction (p = 0.87).

Results of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the number of errors occurring in the *prepareChicken* task. There was a statistically significant difference between types of system malfunction as determined by one-way ANOVA [F (2, 9) = 5.406, p = 0.03]. A Tukey *post hoc* test revealed that number of errors occuring in the *prepareChicken* task was statistically significantly higher in the *simple* system malfunction compared to the *no system malfunction* (p = 0.024). There were no statistically significant differences between the *simple* and *complex* system malfunction (p = 0.164) and *complex* to *no* system malfunction (p = 0.46).

Results of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the number of errors occurring in the *cookChicken* task. There was a statistically significant difference between types of system malfunction as determined by one-way ANOVA [F (2, 9) = 5.152, p = 0.03]. A Tukey *post hoc* test revealed that number of errors occurring in the *cookChicken* task was statistically significantly higher after completing the cooking task in *complex* system malfunction than the *no* system malfunction (p = 0.04). There were no statistically significant differences between the *simple* and *complex* system malfunction (p = 0.88) and *no* system malfunction (p = 0.08). Figure 7.10 illustrates the results of number of errors occurring in the Red Spicy Chicken recipe.

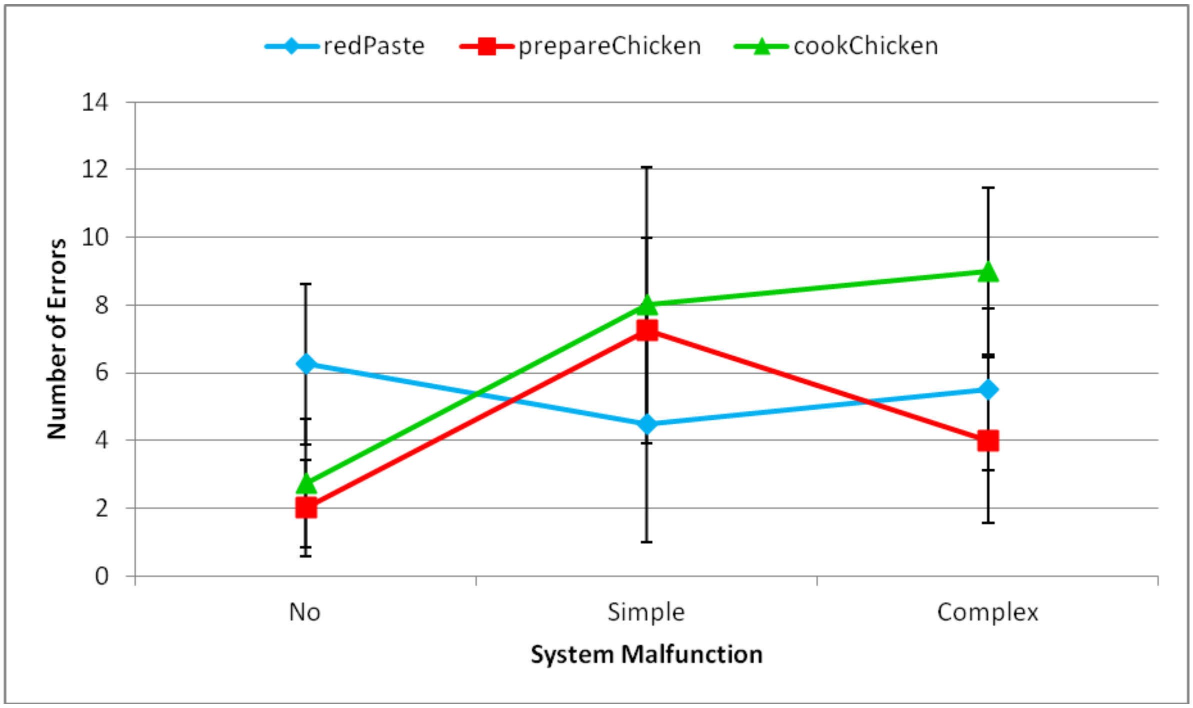


Figure 7.10 Number of errors occurring in the cooking tasks of Red Spicy Chicken with different system malfunction

7.3.3.2 Fish Grill

A one-way ANOVA was conducted that examined the effect of different types of system malfunction and cooking subtask (chilliesPaste, prepareFish and cookFish) on the number of errors occurring in the Fish Grill recipe.

Results of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the number of errors occurring in the *chilliesPaste* task.

There was no statistically significant difference between types of system malfunction as determined by one-way ANOVA [F (2, 9) = 0.181, p = 0.84]. A Tukey *post hoc* test revealed that the number of errors occurring in the *chilliesPaste* task was not significantly different between *no* to *simple* system malfunction (p = 0.86) and to *complex* system malfunction (p = 1). The number of errors was not significantly different between *simple* and *complex* system malfunction either (p = 0.86).

The result of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the steps completed in the *prepareFish* task. There was a statistically significant difference between types of system malfunction as determined by one-way ANOVA [F (2, 9) = 9.500, p = 0.006]. A Tukey *post hoc* test revealed that the number of errors occurring in the *preparechicken* task was statistically higher in the *complex* system malfunction compared to the *no* system malfunction (p = 0.005). There were no statistically significant differences between the *simple* to *no* system malfunction (p = 0.25) and to *complex* system malfunction (p = 0.07).

Results of Levene's Test of Homogeneity of Variance showed that the assumption of homogeneity of variance was met on the number of errors occurring in the *cookFish* task. There was no statistically significant difference between types of system malfunction as determined by one-way ANOVA [F (2, 9) = 0.128, p = 0.88]. A Tukey *post hoc* test revealed that the number of errors occurring in the *cookChicken* task was statistically not significant when compared to *no* system malfunction to *simple* ($p = 0.98$) and *complex* ($p = 0.87$) and *simple* to *complex* system malfunction ($p = 0.95$). Figure 7.11 illustrates the results of one-way ANOVA of number of errors in the Fish Grill recipe.

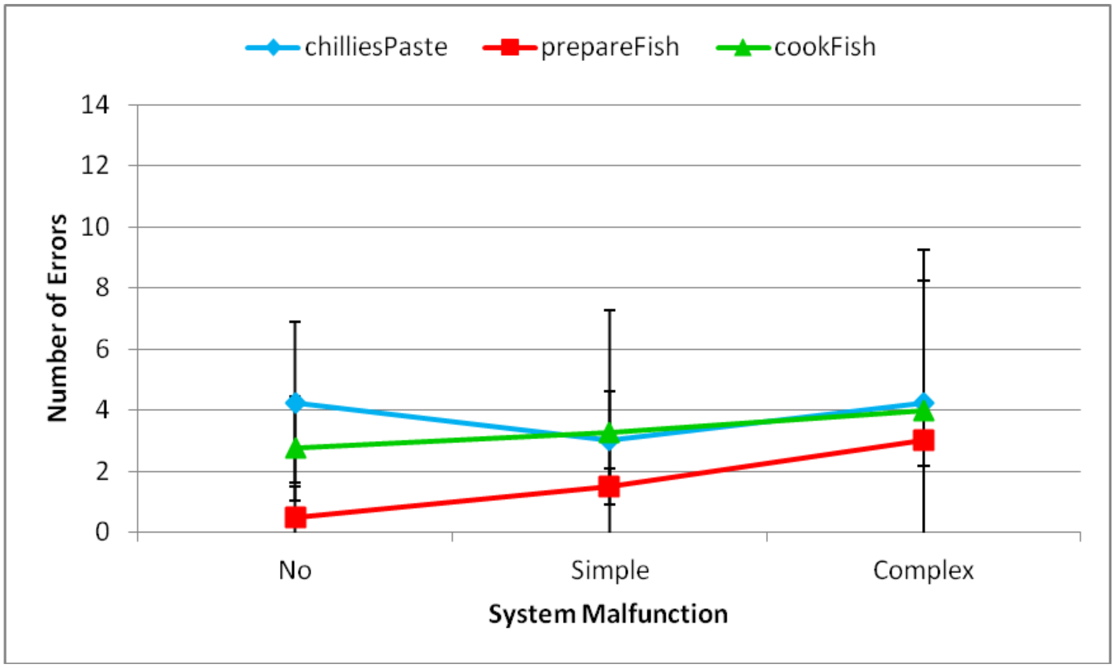


Figure 7.11 Number of errors occurring in the cooking task of *Fish Grill* with three types of system malfunction

7.3.3.3 Summary of Number of Errors

The study found that as level of cooking activity (i.e., the number of steps, ingredients, tools and action) increase, the number of errors made were higher in the *complex system malfunction* (although not in all the cooking tasks). The cooking tasks with a higher number of ingredients had more errors than those with fewer ingredients. The results also show that tasks that have confusion in terms of their name or similar ingredients will cause more errors in the *simple* *system malfunction*. This suggests that *simple system malfunction* involving mixing the right and wrong ingredients does affect the cooking performance when similar ingredients are required e.g. sugar vs. salt, turmeric powder vs. curry powder, or galangal vs. ginger. This also suggests that cooking tasks involving a lot of ingredients such as in the *cookChicken* task, lead to experts getting the ingredients' names confused between the English and the native languages.

7.4 Discussion

The study measured the performance of cooking activities by Malaysian participants (who were all assumed to be experts in the recipes and ingredients) when system malfunctions occurred in an ambient kitchen. It was found that system malfunction slows the performance significantly when compared to a control condition in which no malfunction occurs. For example, one participant complained about the cooking task: *"I thought I already used this ingredient, why do I need to use it again?"* but she nevertheless continued to follow the instructions given. Another participant skipped the 'extra' step after realizing it had confused her. *"This is not right, something weird here, I want to skip this step because I have taken this ingredient; why do I need to used twice?"* This suggests that during the cooking activities in the *system malfunction*, participants *might not* be able to differentiate between the steps of the primary cooking task and the 'other' cooking task. This suggests that users have confidence that the system gives *true* information and is guiding them to accurate completion of the cooking tasks. One participant questioned the distraction. *"This looks strange, ermm (re-read the ingredients* *and instruction) well.. just follow the system, this is what the system wants me to do."* Therefore, participants ended up confusing the cooking tasks.

The cooking tasks with more ingredients had more errors than those with fewer ingredients. The results also show that tasks that have confusion in terms of its name or similar ingredients will cause higher errors in the simple system malfunction. This suggests that *system malfunction* involving mixing the right and wrong ingredients can affect cooking performance when similar ingredients are required i.e. sugar vs. salt, turmeric powder vs. curry powder, or galangal vs. ginger.

7.5 Conclusion

This chapter is the end of discussion and studies of *complex ambient display* which has been discussed earlier in the thesis. Chapter 6 has shown that *ambient* user interface ease the cooking activity in the digital kitchen environment both for expert and non-expert cooks. However, when *system malfunction* occurs in the *ambient* user interface, it does slow down the cooking activities. Interruptions during the cooking contribute to more errors being made. However, some participants ignored the interruptions and follow the *expertise knowledge* to continue cooking while others questioned the system as to whether it give the right or wrong information and feedback.

CHAPTER 8
Conclusions and Future Work

In the introduction, we expressed the hope that the work in this thesis could be a 'first step' towards the study of the Ergonomics of UbiComp (the Ubiquitous Computer) with particular reference to the digital kitchen. In this final chapter, we will conclude by describing the progress made towards this goal in terms of our development of the Stimulus-Response Compatibility (SRC) framework and its application to the UbiComp domain.

The work in this thesis set explores the effect of ambient displays in creating human computer interaction. The first stage of the study was to understand the concept of SRC with ambient displays in cooker-control studies. The reason for this was that SRC is a well established paradigm in the study of Human Factors, and the application of SRC to cooker-controls provides an overlap between the domain of interest for this thesis (the kitchen environment) and a particular Human Factors theory and method. Studies in this thesis employed questionnaire and interaction with a physical prototype. Although some previous studies (Hoffmann, 2009, Liu and Khooshabeh, 2003) stated that paper prototyping is insufficient for supporting SRC, we felt that a questionnaire can be useful in providing an initial perspective to understand user requirements which can then later be supported with hardware prototypes (see Chapter 3). This study also sought to learn if an ambient display can affect population stereotypes in cooker-control (see Chapter 4). From the paper-based questionnaire, SRC was extended to a physical prototype, the *Ambient Stove* (see Chapter 5). This study employed a simple task in which participants were required to choose the correct rotary knob to switch off red, green and blue LEDs.

The second stage of this thesis explored ambient display with more complicated visual information (see Chapter 6). A complex ambient display consists of information (e.g. lights, text, video, interactive icon) shown at the same time in the form of multiple cues. The work started by exploring the advantages of multiple cues in guiding users during cooking activities by displaying a recipe book, lights to cue correct ingredients and interactive icons. This work looked into the potential of a projected display to guide users in step-by-step recipe instructions in the *Ambient Counter.* Third and finally, the work in this study explored the potential impact of system malfunction on human performance during cooking activities (see Chapter 7). Studies in this thesis sought to answer three research questions.

i. How can ambient displays enhance human performance?

ii. How can multiple cues be designed into ambient displays?

iii. What are the consequences on human performance if UbiComp fails?

Specifically, this thesis addresses these questions through three research areas: (i) SRC and ambient display; (ii) ambient display and human performance; and (iii) the effects of distractions, interruptions and other system failures in human interaction with ambient display. The next section will briefly discuss each of these areas and the conclusions drawn from the work in this thesis.

8.1 Thesis Research Area

8.1.1 Stimulus-Response Compatibility and Ambient Display

The over-arching concern of this thesis is the potential application of conventional Human Factors theory and methods to the study of ubiquitous computing (UbiComp). Not only does this provide an opportunity to compare human performance in environments with UbiComp interfaces with those comprising conventional technology, but also means that there is no requirement to invent new theories and methods to address the challenges raised by the new technologies defined by UbiComp. The initial chapters in this thesis concentrate specifically on SRC. In this thesis, SRC has been considered in terms of interaction with ambient displays. This research has explored the potential of ambient display in the cooker control layouts.

A well-known approach to the study of Human Factors in interaction with display (stimulus) and controls (response) involves the concept of 'stimulus-response compatibility.' When a control and display are 'compatible' then it is much easier for a person to use this combination quickly and without making mistakes. In this instance, the term 'compatible' refers to a clear and obvious match between the operation of the control and the behaviour of the object on which the control operates. This match could be defined in terms of movement, e.g. a turning a rotary control clockwise would be expected to move a slider, on a horizontal scale, to the right. Alternatively, the match could be defined in terms of spatial layout, e.g., if a row of buttons is placed under a row of lights, one would expect the button under a specific light to control that light. This latter is termed spatial compatibility and has been extensively explored in terms of cooker controls.

Previous research has looked at SRC of cooker-burner controls using different types of labeling, such as numerical, alphabetical, or sensor-lines (discussed in Chapters 3, 4 and 5). Results from these previous studies show that adding labels can interfere with the naturalness of SRC because it might require the user to 'translate' from the presented information to the control selection. The reason for this is that, rather than seeing the match between a control's position and a burner's location (as is meant to happen in SRC layouts), the user will need to first read and comprehend the labeling and then use this to guide their response. It was proposed that the use of some form of ambient display could provide support for the 'natural' mapping in SRC by reinforcing the correct response. Alternatively, the provision of additional, redundant information could either slow the user's response (particularly if conflicted by the SRC) or have no effect on performance.

The first stage of the study involved a paper-pencil test (questionnaire) which was conducted as a preliminary test before a hardware test could be developed and tested. Three different forms of ambient displays were shown to participants in four control-burner layouts; red light emitting diodes (LEDs) on the hob simulated whether a burner is lit, blue LEDs mounted on the underside of the 'hood' indicate a 'lit' burner (for instance, when a pan is covering the burner) and green LEDs mounted on the front of the 'hood' are in line with the controls (see Figure 3.3, Chapter 3). Two types of cooker-burner layout were considered; linear and quadrant with two types of ambient display arrangements; compatible and incompatible. This approach aimed to identify preference for control-burner layouts under these different arrangements. Linkage III became the baseline for the comparisons as the findings from previous research (Hsu and Peng, 1993, Wu, 1997) had shown that Linkage III was the preferred linkage. Figure 8.1 illustrates Linkage III.

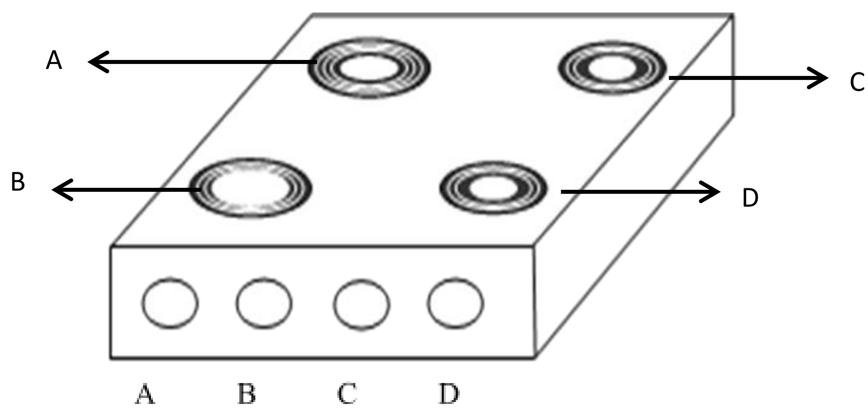


Figure 8.1 Illustration of Linkage III cooker-control preference

Results from the pencil-and-paper test showed that (in agreement with some of the previous studies), Linkage III is the preferred arrangement, but this is only the case when there are two or three LEDs and only in the 'compatible' condition. This result also contradicted other previous findings which had shown that Linkage III was the dominant control-burner mapping when the burner (which corresponds to a single red LED in our study) was shown. In other words, previous pencil-and-paper tests presented respondents with a single coloured item on the stove-top (indicating the burner) and found that people tended to prefer Linkage III. This was not the case in this study, and the preference for Linkage III became stronger when there was additional, redundant information (in the form of other coloured marks on the stove). In the quadrant control-burner arrangement, Linkage III was the dominant choice regardless of the number of combinations of LEDs and whether the arrangement was compatible or incompatible.

From these studies, it was suggested that provision of additional information (in the form of a second LED) could enhance consistency of response in the control-burner selection task. This led to the construction of a simple physical prototype which supported reaction time experiments

8.1.2 Ambient Display and Human Performance

To develop the ideas from the paper-pencil tests, the ambient display in the cooker control was further explored by using a ‘real’ hardware prototype named Ambient Stove. Light Emitting Diodes (LEDs) are embedded to represent these ambient lights in the prototyped stove model. By connecting the LEDs to rotary controls and stop watches (see Figure 5.2, Chapter 5) reaction times could be measured in these experiments.

This study showed that the number of response attempts is lower when there is high spatial compatibility between the LED and control (both in the compatible and incompatible arrangements). In other words, when considering response times to single LEDs (red, blue or green), responses to green LEDs (green LEDs are in line with the control) are faster than to the Red and Blue LEDs. While it might be expected that responses to Blue LED (which is 'hidden' from view) may affect responses, the results show a slightly better performance for Blue LED than for Red LED. However, response times are slower in the incompatible arrangement compared to the compatible arrangement in all sets of single LEDs.

As the number of LEDs increases from one to two or three, reaction times become faster than for single LEDs. This suggests that additional, redundant information can enhance responses. From this, we say that additional information does help users make a decision provided the compatible arrangements are given. However, additional information in an incompatible arrangement produces the worst performance.

A further study was conducted in the Ambient Counter (see Chapter 6) to test the effectiveness of additional information. Results from this study suggest that an indirect form of interaction, using *smartChalk*, makes it more likely that participants will make errors while cooking. This is due to the fact that 'indirect' interaction causes participants to perform two different tasks; 'cooking' and 'pointing'. Indirect manipulation leads to the greater impairment in performance by 'expert' (Malaysian) participants than by 'non-experts' during the cooking activity.

On the other hand, this study also showed that direct manipulation (in which user action on objects in the environment results in changes to the projected display) leads to superior performance over a traditional recipe book. This suggests that performance of cooking activities is improved by the ambient display as it provides a ‘natural’ interaction between user, tools and ingredients. More interestingly, the ambient interface enhanced performance of the ‘expert’ (Malaysian) participants.

8.1.3 Distraction, Interruption, Ambient Failing and other System Failures

Chapters 3 to 5 explored simple ambient displays and suggested that increasing the amount of information (i.e. providing multiple cues to the user) could enhance performance when there is no incompatibility in the cues provided. However, when the cues did not agree with each other, performance was seriously compromised. It would appear that participants were not able to ignore the conflicting information and became distracted. Therefore, a further study was conducted on distraction and interruption of ambient display through a complex ambient display, to understand whether the concept of ambient display actually improves or enhances cooking activities.

Extending the study in Chapter 6, a study to understand how ambient distraction can interrupt a cooking study was performed (see Chapter 7). Two types of distraction were given during the cooking activities without being known by the participants; simple distraction and complex distraction. Simple distraction involved the ambient display highlighting an ingredient with incorrect information (red lights) when it was the correct ingredient. Chapter 6 shows that participants tend to confuse ingredients that have similar characteristics such as physical appearance, colour or name (i.e., salt versus sugar). Complex distraction is a combination of simple distraction and distraction steps, i.e., a step from a different recipe. This could represent a situation when the automatic prompting confuses one recipe with another.

This study shows that complex distraction slows performance significantly in terms of cooking times and suggested that participants are confused by the 'extra' step involving other recipes which have similar ingredients. This study showed that fewer steps are completed in the complex distraction. However, the error-rate was higher in the simple distraction, showing that distraction of ingredients confuses participants. This suggests that participants tend either to rely on their own expert knowledge and ignore any displayed information (as they are familiar with the recipes and ingredients) or to follow, believe and trust the information given by the system.

The next section will synthesize the empirical findings to answer the study's research questions.

8.2 Answers to Research Questions

In summary, it is believed that the work conducted in this thesis answers the research questions that were originally posed: a projected ambient display in the cooker and augmented kitchen has been developed which allows natural mapping in the digital kitchen environment. Furthermore, the study demonstrates a simple approach to designing digital interaction using visual cues that are flexible and can be used to encapsulate a large variety of techniques and criteria for the digital kitchen environment.

This thesis sets out to answer the questions put in Section 1.5. These questions have been addressed within this thesis as follows.

a) **How can ambient display enhance human performance in the digital kitchen?**

The studies in this thesis show that human performance is better when there is compatibility between the cues, and incompatible arrangements make the performance worse and lead to confusion. While the focus of the studies was on a specific domain and specific tasks, it is proposed that the work contributes more broadly to Human Factors and SRC. As noted previously, SRC can be defined as the agreement between control and responses: if control and response are in the 'same' position to each other or if visual cues show a 'direct' cue as to which controller to respond to. In the cooking activity user trials, human performance improved when there is a direct manipulation between users, tools and ingredients. Ambient displays give a 'natural' interaction between the environment and users. In this case, 'natural' simply means dependent on SRC (for cooker controls) or a direct mapping between object and information displayed in the ambient counter. This allowed users to perform cooking activities without any distraction and interruptions. In terms of guidance for UbiComp systems, these findings suggest that basic principles of Human Factors (in the form of SRC) can prove useful in the design of UbiComp. Designers of UbiComp can consider the types of action (response) that a given user will be expected to perform and seek ways in which this response can be directly linked to ambient displays, which can either cue a specific action or provide advice on actions to perform in sequence.

b) How can multiple cues be designed in the digital kitchen environment?

Work in this thesis has shown that multiple cues assist users when there are direct mapping cues with the respective objects/responses. Multiple cues allow users to perform better than they do when using a single cue. However, multiple cues should be shown or respond to current users' behaviours rather than provide pre-setup instructions by the system. In other words, the cues should synchronize with the users' actions expected for both the expert and non-expert user (i.e. cooking activities). Moreover, if there is a missed action in one particular step (i.e. missing added ingredients), cues should be given to users before continuing with the next action to be performed. However, this warning should not be repeated until a certain number of warnings have been given; this will avoid users becoming confused or frustrated with the system. These cues can be presented using coloured lights to indicate the missing ingredients or to highlight ingredients that have already been used.

Designers of UbiComp can benefit from incorporating redundant (additional) information in their cueing, as this seems to enhance user performance. If the technology supporting UbiComp (such as activity recognition) fails, it would be better to provide no cues than to provide conflicting cues. From this perspective, it might be useful to have a threshold (say, in terms of confidence levels for activity recognition) which the system output needs to meet before ambient displays are used - and, if the output is below this threshold then cueing ought to be removed because it is likely to significantly impair performance.

c) What are the consequences on human performance of ambient display failure?

These studies have shown that if ambient displays fail, user responses will be varied and confused. In the cooker-control studies, preference for Linkage mappings becomes diverse, particularly as the number of cues increases in the incompatible arrangements. There will be no agreement on the cooker mapping linkages when there is an incompatible arrangement within the population stereotypes of cultures. In the complex ambient displays, users tend to follow the information given by the system even though the information given is wrong.

8.3 Limitations of Research

As with any PhD. thesis, there are some limitations in this study. The sample composition, i.e. number of participants for each study, could be a critical factor. Although previous research has used hundreds of participants as a sample size, particularly when considering population stereotypes and cross-cultural comparisons, the relatively small sizes in these studies might be sufficient to provide comparisons with previous work on SRC but are likely to be too small to provide confidence for cross-cultural comparisons. Having said this, problems of sample size were addressed through the application of the appropriate statistical adjustment in the analysis of the results.

A second limitation is the cooking activity. Limited access to a ‘real’ kitchen environment may affect the performance of ‘real’ cooking activities. However, health and safety reasons removed access to a ‘real’ cooking task. Consequently, a participant may not be able to perform ‘real’ cooking activities. However, video analysis has shown that participants were able to understand the task that was needed to be performed and this provided a means of comparing performances using different interaction devices.

A third limitation is the restricted nature of the domain explored. The kitchen environment was selected as this was felt to be both a good proxy for developments in UbiComp (particularly in terms of projected displays or in terms of the use of LEDs to provide feedback and cues to users) and that the kitchen represents a domain which is receiving a great deal of interest as a potential space to deploy UbiComp. While the study has concentrated on the use of a cooker and the ability to follow instructions in a recipe, it is proposed that the findings could be extended to other activities which involve interaction with everyday technology or which involve following procedures and sequences of instructions.

8.4 Future Work

The objective and goal of this research is to provide a *groundwork* that will benefit future directions of UbiComp. A number of open problems must be solved to allow the development of UbiComp in general and the ambient kitchen in particular. These problems suggest a variety of research directions that need to be pursued to make such environments feasible.

One such direction would be to have access to a fully equipped and working digital kitchen (smart kitchen) such as in MIT and Newcastle, to improve this study into further areas of research. The use of a smart kitchen would allow a greater range of tasks to be explored. However, it is proposed that simply presenting people with more tasks to perform need not lead to results which challenge or contradict those found in this thesis. Even though the studies in this thesis have used rudimentary forms of ambient display, the results are, it is believed, able to be generalised to apply in more complicated environments. What would be interesting is the extent to which ambient displays can cue a wider range of actions in cooking activity. Another possibility would be a digital kitchen that has a full spectrum of ambient display embedded into cooking equipment and tools such as stove, refrigerator, microwave and utensils. This would provide the opportunity to test stimuli response compatibility in terms of a wider range of products and tasks. The challenge here would be to devise new forms of SRC, i.e. beyond movement and spatial compatibility, to consider different ways of defining task compatibility. For example, Carswell and Wickens (2000) proposed the concept of a proximity compatibility principle, in which spatial compatibility is combined with the idea of task compatibility (i.e. agreement with the users' expectations of how to perform the task). While their work developed the spatial compatibility notion, the idea of task compatibility is still to be developed. For example, experimental work and analysis can be done within a country or demography which has different races and cultures (e.g. Malaysia). Access to these smart kitchen and ambient displays are more interesting if multiple cues exist in the environment, such as lights, voice, video, text or pictures embedded in the environment and the tools.

Additionally, having access to the digital kitchen environment would allow 'real' user trials to be undertaken. Although many studies have been done in the digital kitchen environment, none have been concerned with testing the environment with real user trials by using 'real' participants, ingredients and equipment. Within this study, an ambient display of recipes will be shown based on 'current' cooking activity. This can be done by tagging Radio-Frequency Identification (RFID) to the equipment and ingredients being used in order to know the 'current' stage of cooking activity. Mistakes during cooking activity can be detected by identifying the wrong activity made through RFID and this can be a warning through an ambient display embedded into the kitchen environment. This can reduce the disruption within the cooking activity. If the disruptions come from 'outside' the cooking activities, such as a phone call, cooking activities may resume showing the interaction of the cooking navigation with ambient display.

8.4.1 Implementation of Ambient Cueing in others UbiComp Research Area

Overall, the work in this thesis has mainly shown the impact and consequences of direct mapping of ambient display/cueing, multiple and failing cues in the domestic digital kitchen environment. Ambient display allows users to experience occasionally without it interfering with their primary tasks, and is well-suited to provide feedback on their personal activities in a more subtle manner. Ambient displays are not only limited to the colour displays but can also exist in the form of animation, sense, position, visualisation, audio and tactile senses.

In general, the aim of ambient display is to explore a new way of introducing information in the everyday environment (Holmquist and Skog, 2003) and the ambitious goal of ambient display is to present information without distracting or burdening users (Mankoff et al., 2003). Thus, ambient display research is not limited to home or domestic environment but can be extended to different levels of studies involving any human-computer interaction. We will review some of the works that can implement ambient displays by taking advantage of the results found in this work.

A natural and popular application for Ubicomp is in providing assistance to people who need help in their routine activities. With the advantages of direct mapping found in this thesis, a further work on guiding them through ambient display can be done. For example, with the technology of sensors and indoor GPS, floors can be embedded with ambient lights to guide them to specific locations such as from bedroom to toilet, from one store to another store (in the shopping mall) or alert them with cues that can remind them of things to do. The research in this area can focus on those people who need special assistance, such as the elderly.

A further work with the advantages of direct mapping can also be implemented in other types of guidance activities. Take a museum tour guide for example. While a number of studies have focused on developing a complex and interactive robot (Burgard et al., 1999, Thrun et al., 1999, Thrun et al., 2000, Nieuwenhuisen et al., 2010) which incorporates body language, gestures, facial expression and speech, ambient display brings a new perspective to human-computer interaction in the museum tour guide. For instance, ambient display can guide users to the next topic of interest or artefacts based on history or previous artefacts that have been visited. The cues can either be in terms of colour (guide user to next interesting artefacts), visualisation (draw user's attention to interesting visual cues on next artefacts) or in audio as in adapting to its visitors' preferences. Although Chen et. al (2011) developed a prototype of a mobile interactive museum guide system, we believe that system still does not support 'natural' interaction between the user and computers as it required a mobile PC equipped with a webcam to retrieve multimedia information about the objects of interest.

The work can also be further explored in shopping guides. There is a number of works which have been done in developing shopping guides by using location-awareness (Bohnenberger et al., 2005, Gross et al., 2009, Mathankumar and Kavitha, 2013) which works mostly focus on guiding a shopper to possible locations of products to minimize the time required and maximize the likelihood of finding the products. By using multiple cues of ambient displays, the potential for shopping guides can be further explored to guiding shoppers to choose the correct products before buying them, by displaying necessary information. Ambient displays can be used to compare the product with different brands by giving detailed information such as calories, ingredients, and origin. With the information given, ambient display can *persuade* the shopper to buy healthier or valuable (quality) products and suggest suitable products that are within the shopper's budget. Ambient display can also be used to alert the shopper to distinguish differences of the brands on these products to give more choices.

In the entertainment research area, ambient display can be used in interactive board games such as chess, solitaire, noughts and crosses which, by using ambient display, will help or guide a player by suggesting the steps that need to be taken if player is unsure. However, an extension to guidelines or rules is needed to determine at which level of a game the ambient display can interrupt or guide the player. If not, the fun and joy of playing will be lost as the challenge of playing the games is not from the player but from the computer.

Another interesting area of research that can be explored is in the education sectors. It will be interesting to see how interactive ambient display can influence or attract children to learn when they are at home (home-education). Instead using Ipad or tab through apps that can be downloaded from Apple Store or Play Store, using direct and multiple ambient cues at home may encourage them to learn and play at the same time, by manipulating responding to cues embedded in their study's table, floor or walls.

Therefore, the research of ambient display is not limited to domestic environments only; a variety of technologies can be used to enable ambient display in our environments such as Bluetooth, RFID, ICT implant, sensors, software agents, affective computing, nanotechnology and biometrics. Basically, ambient displays are created in order to make our everyday environment sensitive, adaptive and responsive to the presence of people, disappear within our environments so that it can sense people's states, anticipate and perhaps adapt to their needs. Overall, ambient display provides rich opportunities for information display because they are can distributed in any environment.

8.5 Thesis Contribution

The novel significant contribution of this thesis can be summarized in point form

- **Developing a natural linkage mapping in the cooker control layout:** This thesis has demonstrated a new form of cueing the stimulus-response task by using ambient displays as additional information to support cooker-control responses, which actually does provide a natural mapping by eliminating suggestive effects found previously.

- **Multiple cueing of ambient displays**: This thesis has also demonstrated multiple cueing (i.e. combination of two or three ambient displays) into a cooker stove layout. This multiple cueing is developing to accommodate a new human-computer interaction, which supports multiple simultaneous tasks in one particular environment. This approach is taken to understand how users can accommodate and adapt to a new life approach in future.

- **Ambient counter with user trials:** Many previous researchers have developed a high-tech kitchen environment. However, less work has been done to test this augmented kitchen with 'real' user trials of cooking activites. This thesis has taken the first step to test this environment with cooking user trials. By using different groups of participants, real ingredients and equipment. the first phase of the user trials has been performed with three different sets of interaction layouts.

- **Cooking user trials with different interaction layouts:** This thesis has shown cooking user trials by using three different sets of interaction layouts; recipe book, ambient and *smartChalk*. These layouts are being tested on top of the ambient counter to test which layouts give the benefits of cooking activities. The test has compared how these layouts affect cooking activities to allow the designer to explore realistic ambient interaction available for augmented kitchen reality.

- **Testing a disruption/interruption in the cooking activities**: Findings suggest that incompatibility 'message' during the cooking activities interrupt the process and will slow the tasks. Therefore, the thesis has tested which level of disruption will affect the whole cooking process or just part of the process. Although a few researchers have performed this type of testing, none have tested what happens if there is a system malfunction within the ambient information itself. This thesis has looked into this approach.

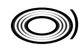
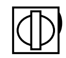
8.6 Conclusions

In summary, it is believed that the work conducted in this thesis answers the research questions. Furthermore, this thesis offers an approach of modelling stimulus-response compatibility of a cooker stove that is flexible and can be used to encapsulate a large variety of ambient displays of the augmented environment in the future. It was claimed that the approach shown in this thesis provides the user with visual cues information which can easily be understood and responded to, and allows users to make informed choices about the environment.

The present study of ambient displays has shown a new approach of modelling human computer interaction ("HCI")in the digital environment. It is not said that the previous works are not valid, but with current ‘invisible’ technologies embedded into our everyday domestic settings, it proposes a new method of handling this new HCI that needs to be designed and tested. Still, the previous studies have given us a background in which to open a broader view and method for future research. Therefore, the approach taken in this study has provided a ‘naturalness’ interaction between the users and environment as it supports direct interactions with users, tools and the environment.

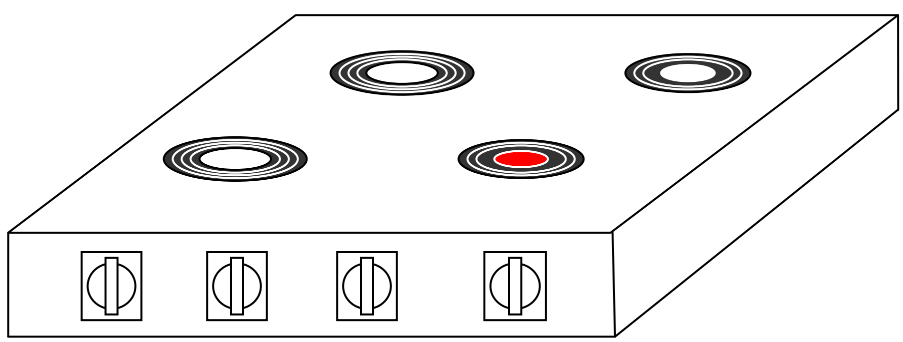
APPENDIX A: QUESTIONNAIRE OF LINEAR COOKER CONTROL

Instruction:

On each scenario, there will be four stoves with different layout of controls and lights. Each stove consists of hob rings (), rotary knobs () and coloured indicator lights. On each stove, you need to mark the rotary knob with 'X' to meet the stove's compatibility requirement.

Trial:

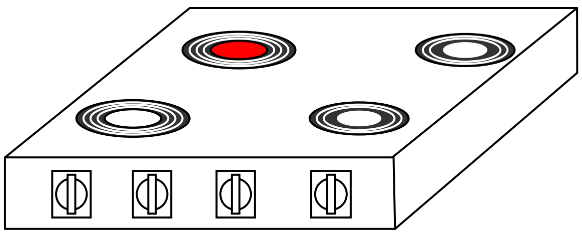
In this stove, given that one of the hob ring's light is on, choose which rotary knob is used to switch off the light. Mark your chosen rotary knob with an **X**.



Scenario One:

One of the lights on the burner ring is on. Which rotary knob is used to switch **off** the light? Mark your chosen rotary knob on the each stove with an **X**.

I)



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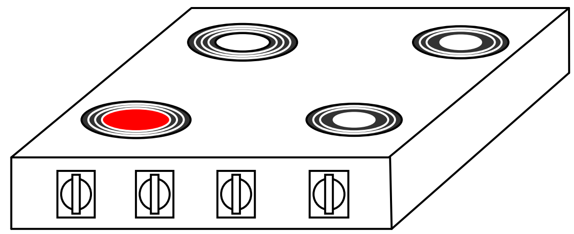
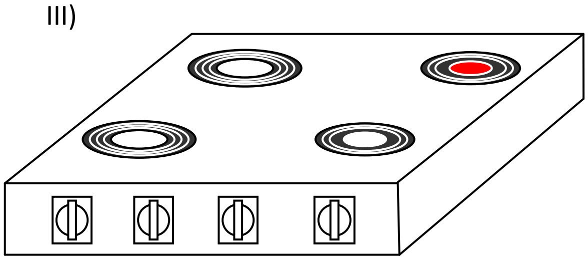
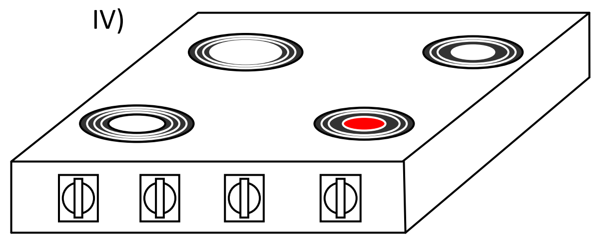


III)



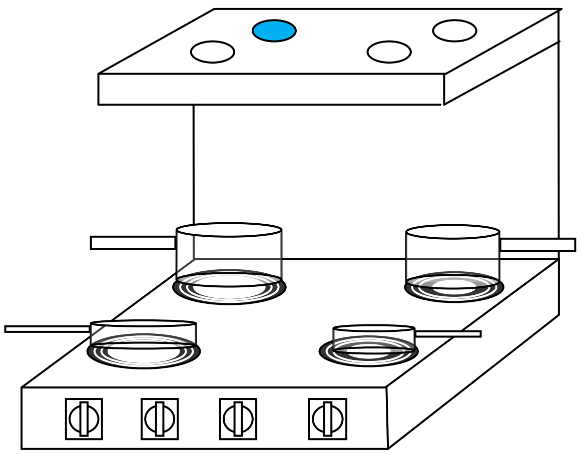
IV)



Scenario Two:

In this scenario, the light above the burner ring is on. Which rotary knob is used to switch **off** the light? Mark your chosen rotary knob on each stove with an **X**.

I)



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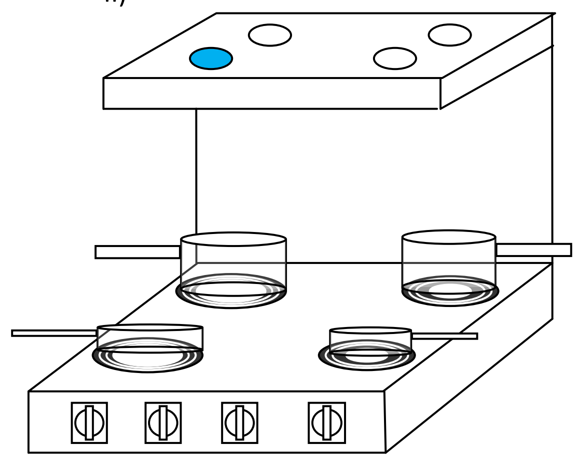

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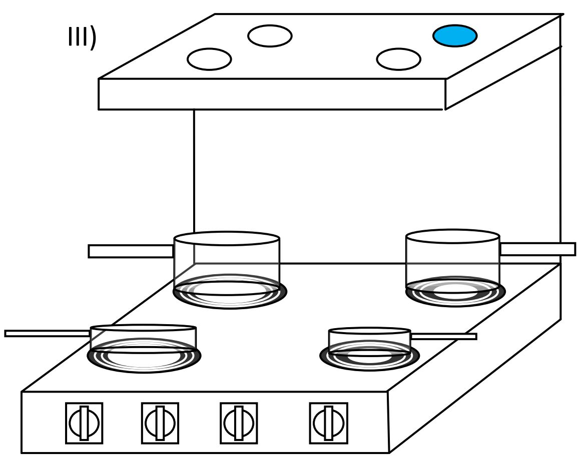

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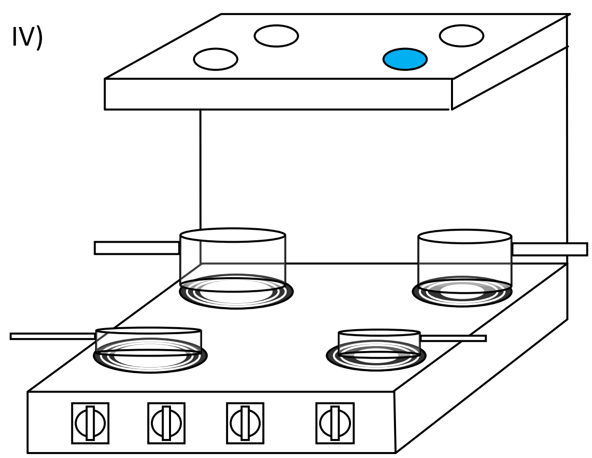
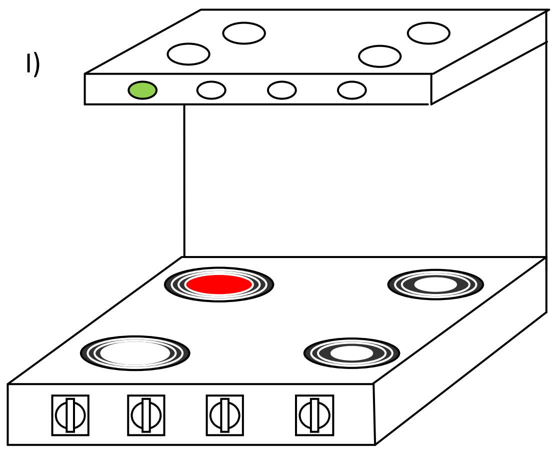


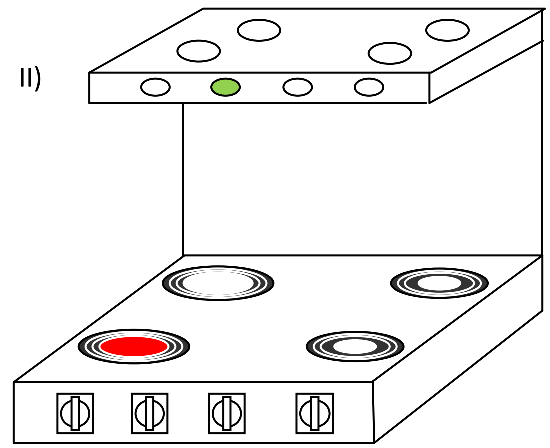
Scenario Three:

In this scenario, the green and red light is on. Choose which rotary knob is used to switch **off** the **RED** light. Mark your chosen rotary knob on each stove with an **X**.

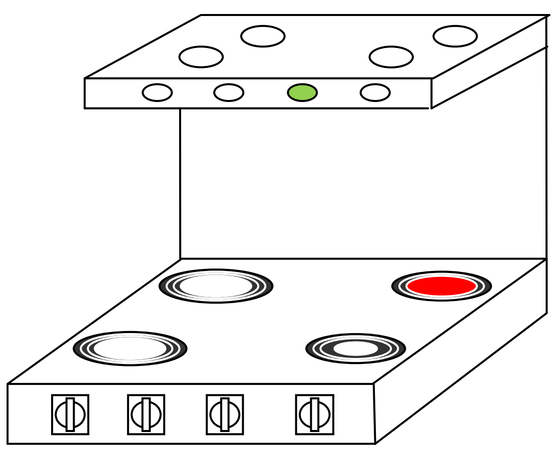
I)



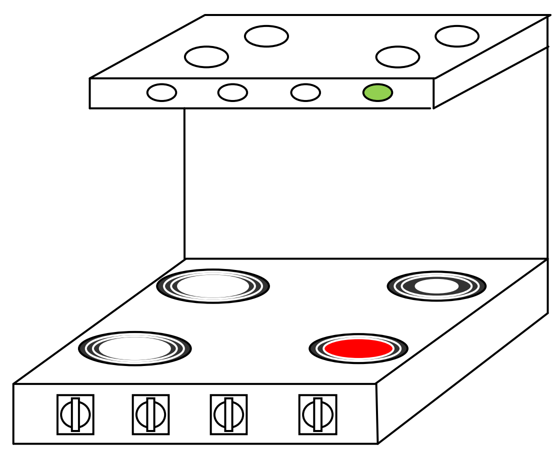
II)



III)



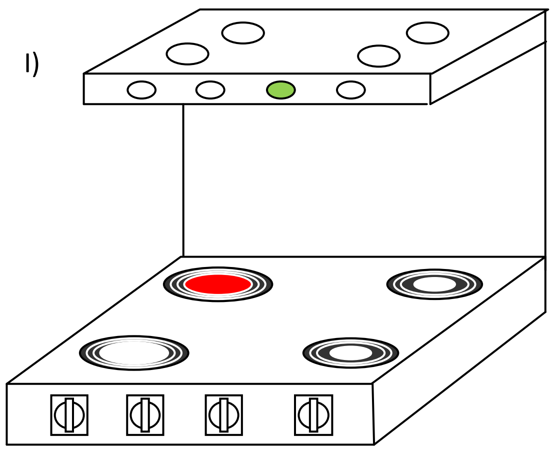
IV)



Scenario Four:

In this scenario, the green and red light is on. Choose which rotary knob is used to switch **off** the **RED** light. Mark your chosen rotary knob on each stove with an **X**.

I)



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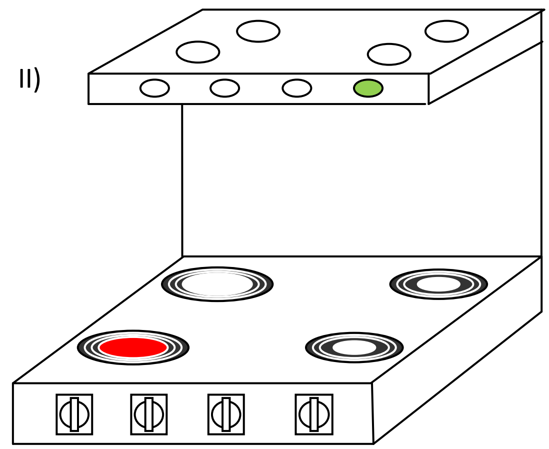
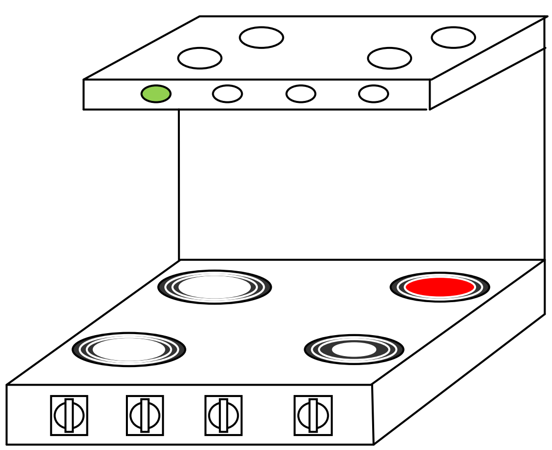
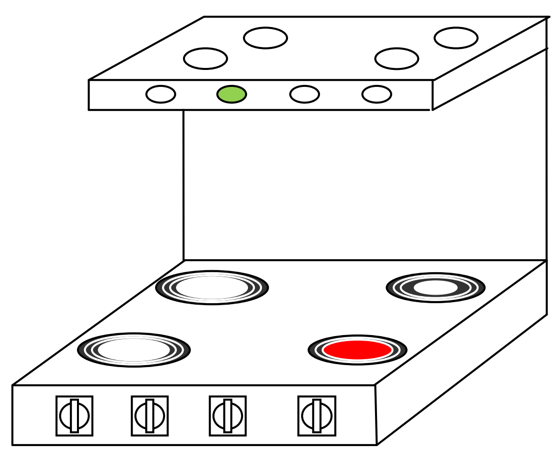


III)



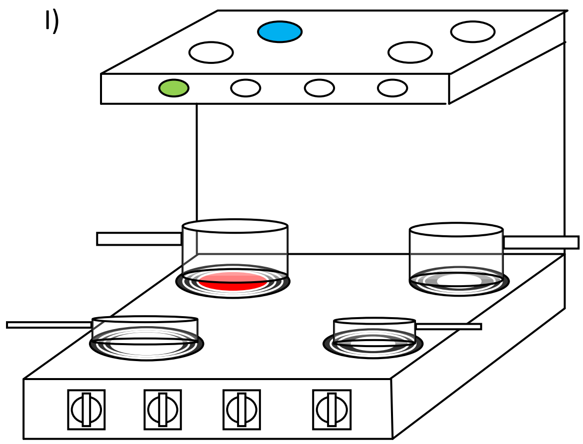
IV)



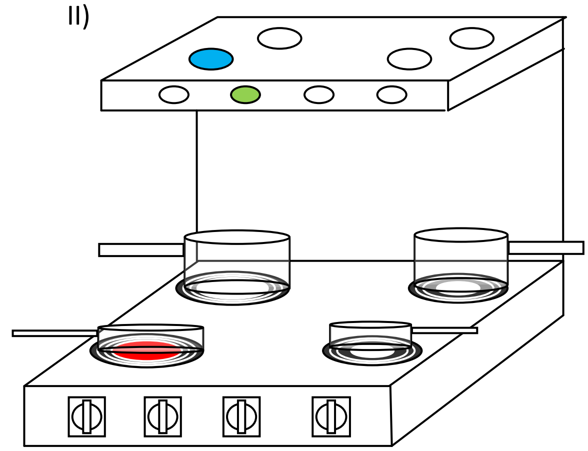
Scenario Five:

In this scenario, the blue light on top of the burner ring is on, followed by the red light. Then, the green light is on. Choose which rotary knob is used to switch **off** the **RED** light. Mark your chosen rotary knob on each stove with an X.

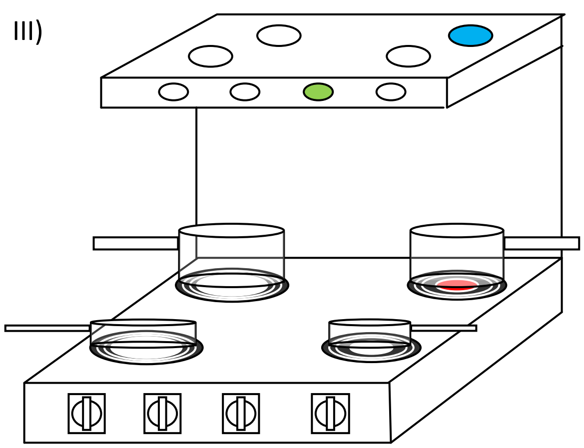
I)



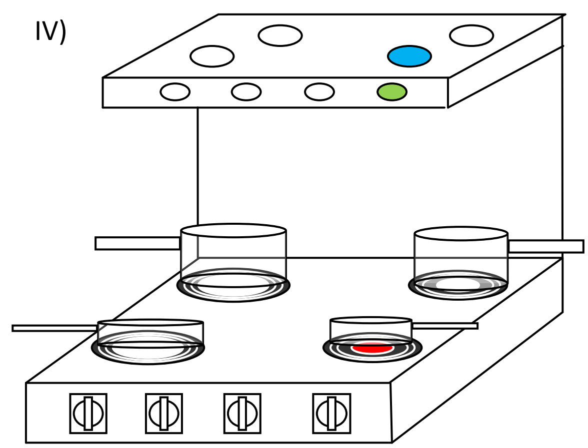
II)



III)



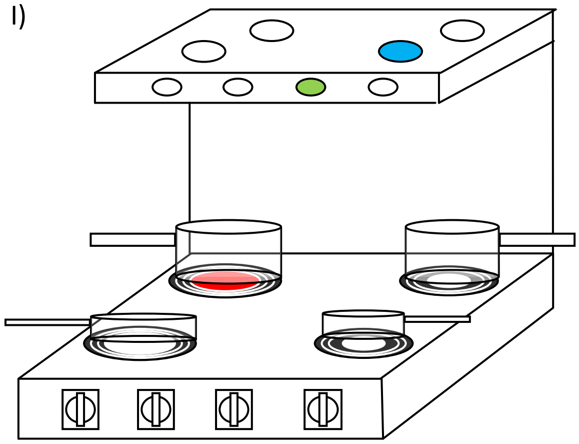
IV)



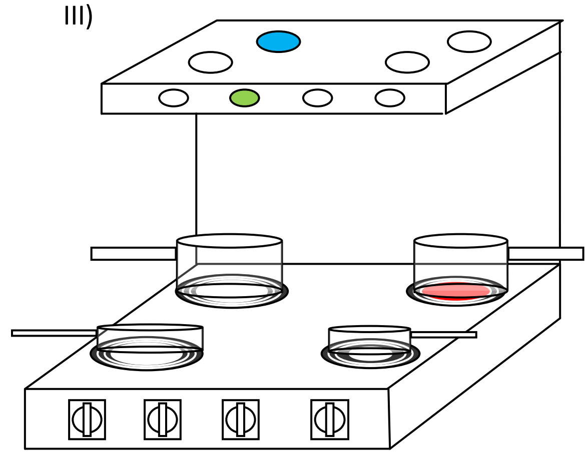
Scenario Six:

In this scenario, all sets of lights are on; red, green and blue. Choose which rotary knob is used to switch **off** the **RED** light. Mark your chosen rotary knob on each stove with an **X**.

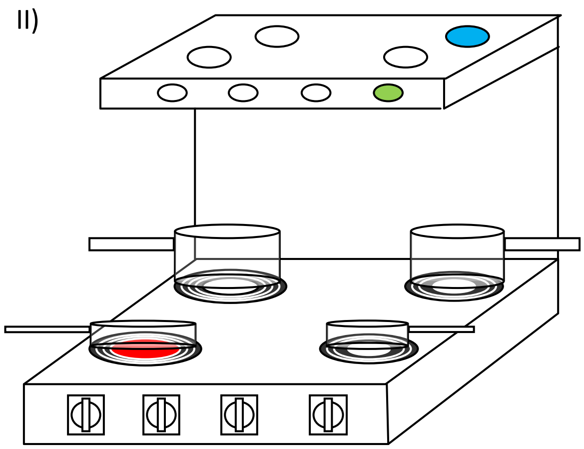
I)



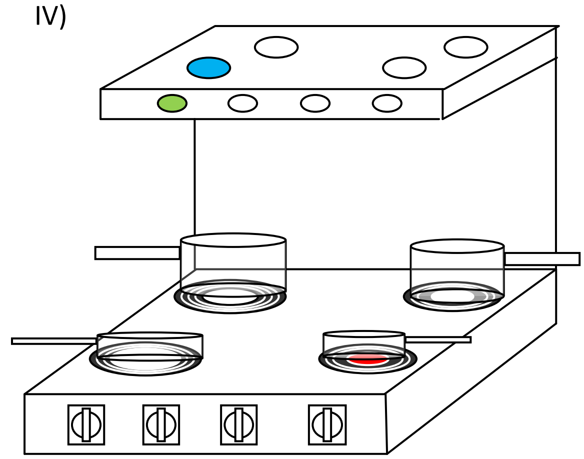
III)



II)

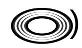
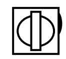


IV)



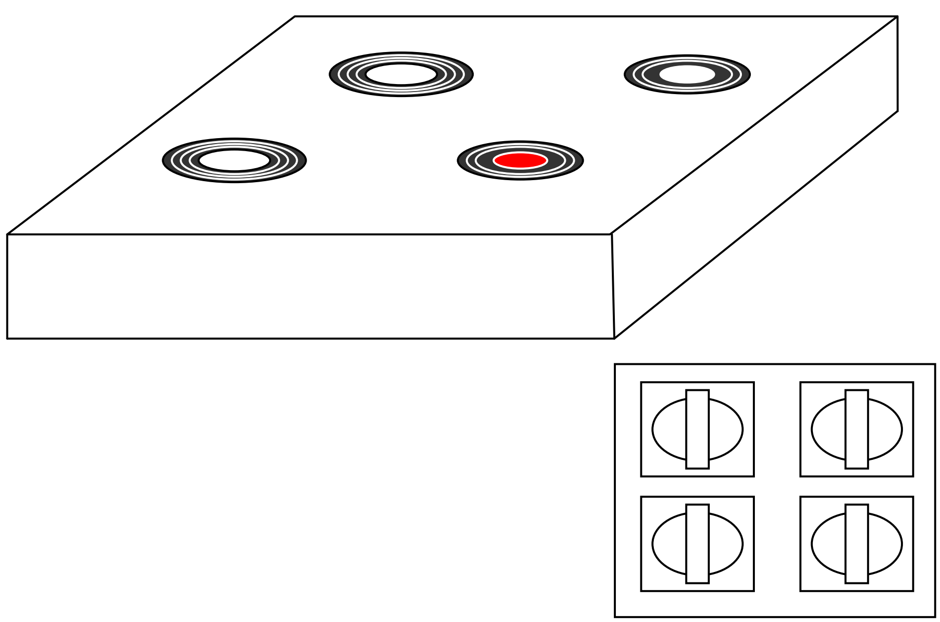
APPENDIX B: QUESIONNAIRE OF QUADRANT COOKER CONTROL

Instruction:

On each scenario, there will be four stoves with different layout of controls and lights. Each stove consists of hob rings (), rotary knobs () and coloured indicator lights. On each stove, you need to mark the rotary knob with 'X' to meet the stove's compatibility requirement.

Test:

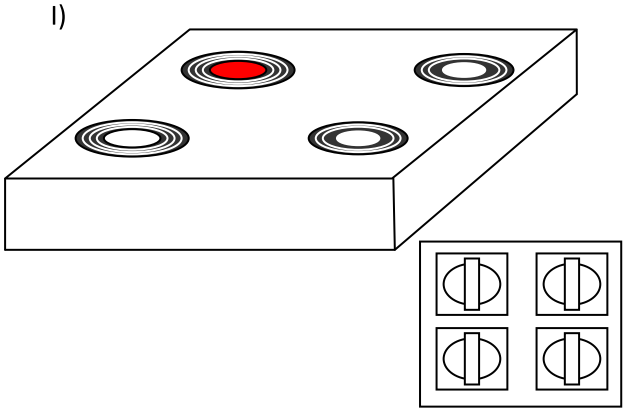
In this stove, given that one of the hob ring's light is on, choose which rotary knob is used to switch off the light. Mark your chosen rotary knob with an **X**.



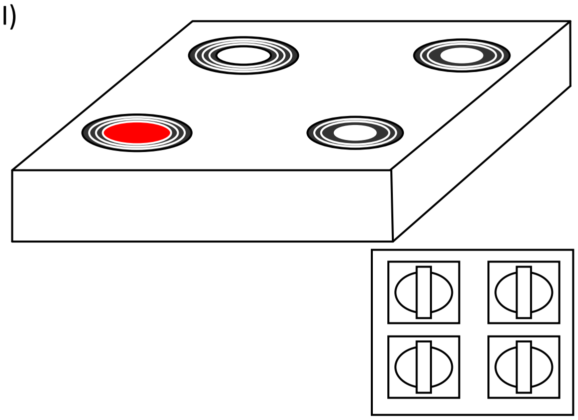
Scenario One:

One of the lights on the hob ring is on. Which rotary knob is used to switch **off** the light? Mark your chosen rotary knob on the each stove with an **X**.

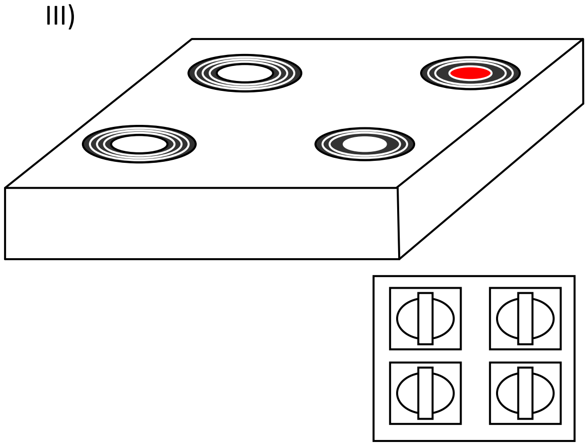
I)



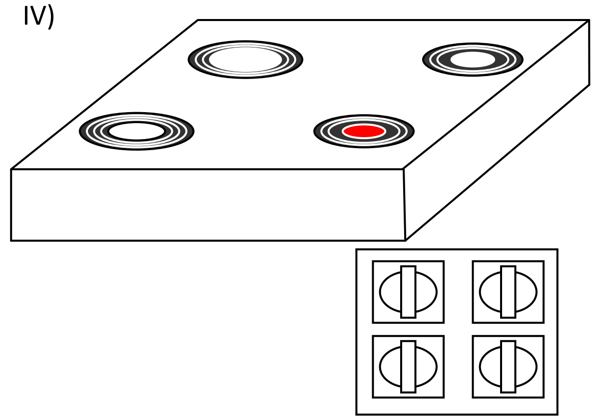
II)



III)



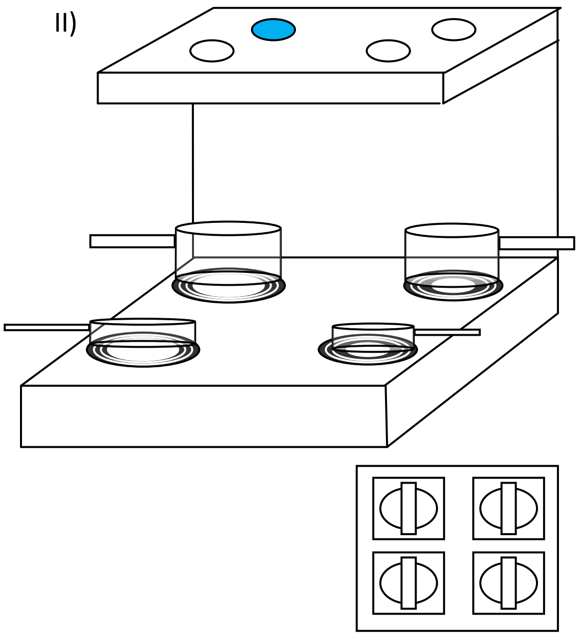
IV)



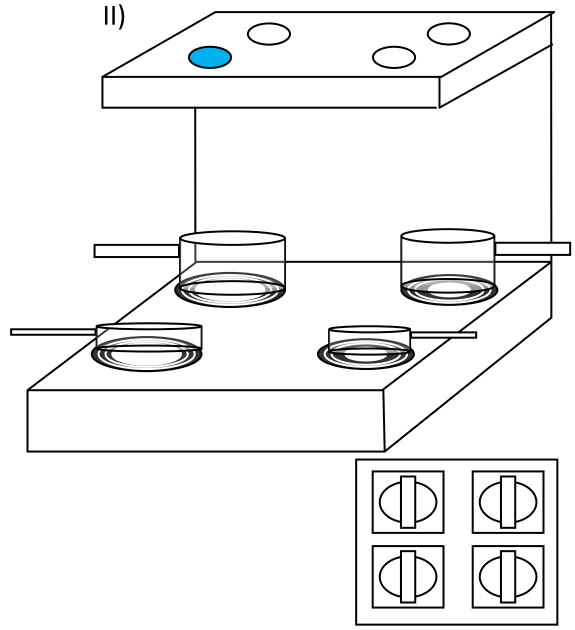
Scenario Two:

In this scenario, the light above the hob ring is on. Which rotary knob is used to switch **off** the light? Mark your chosen rotary knob on each stove with an **X**.

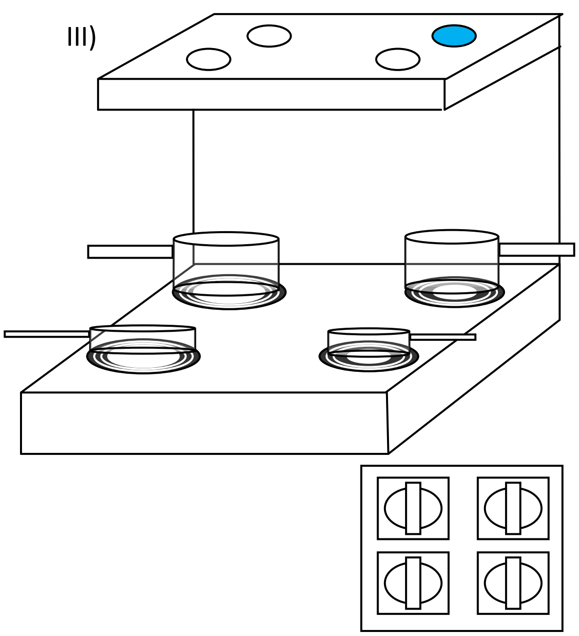
II)



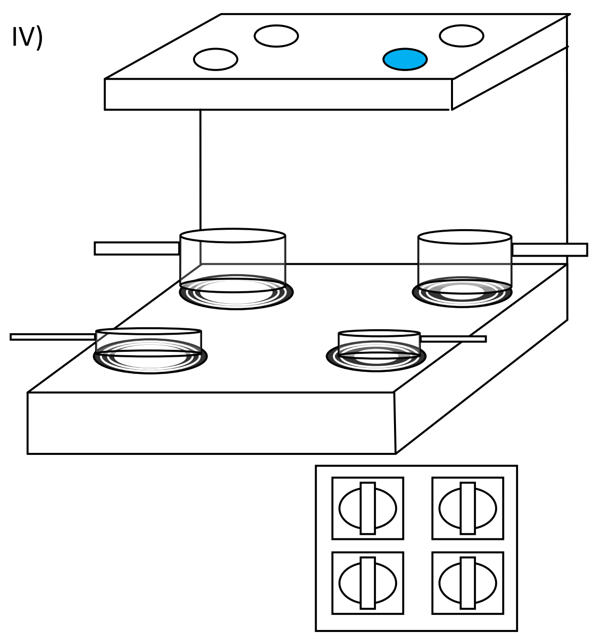
II)



III)



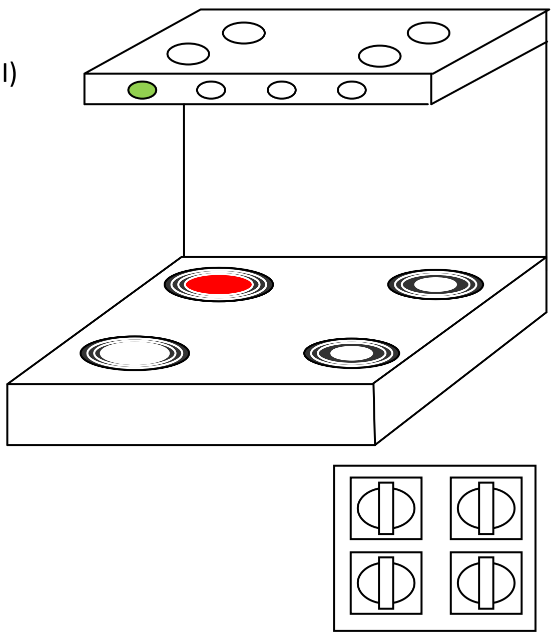
IV)



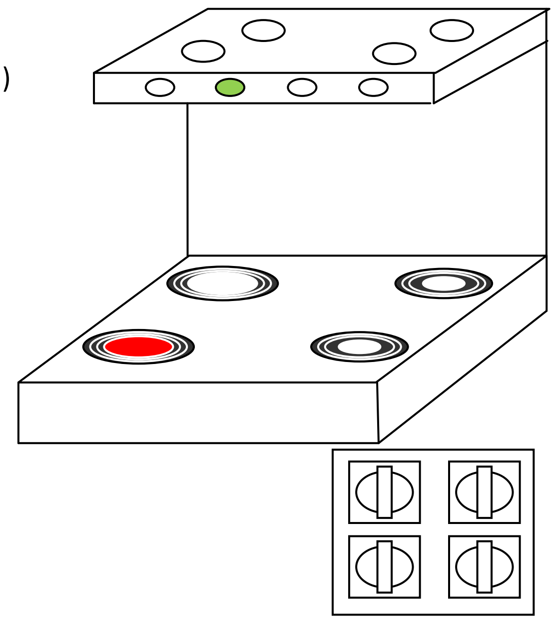
Scenario Three:

In this scenario, the green and red light is on. Choose which rotary knob is used to switch **off** the **RED** light. Mark your chosen rotary knob on each stove with an **X**.

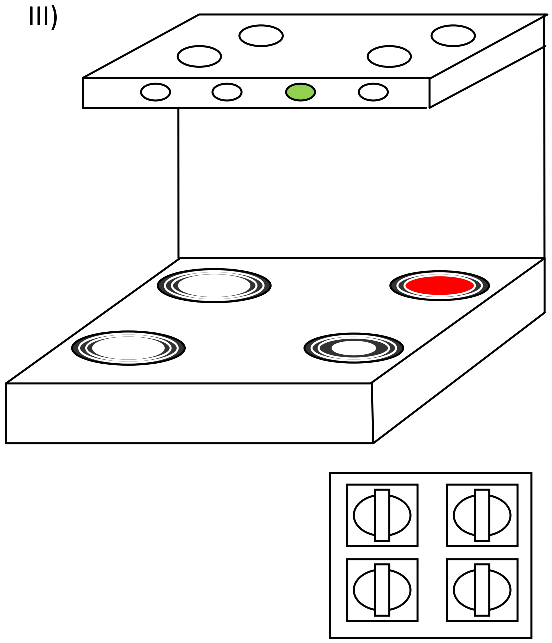
I)



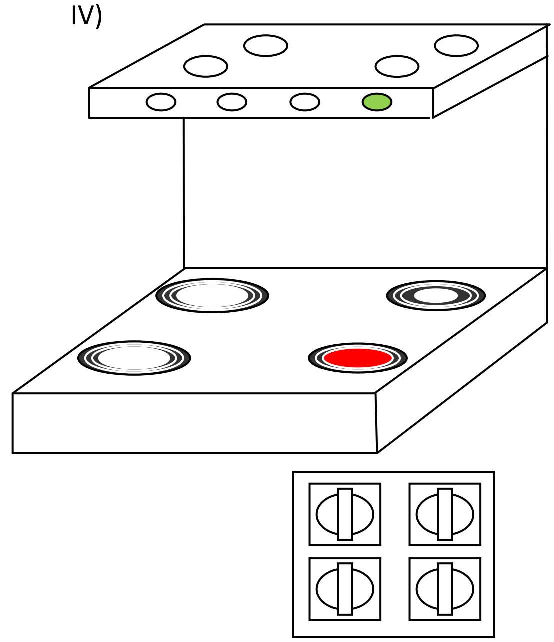
II)



III)



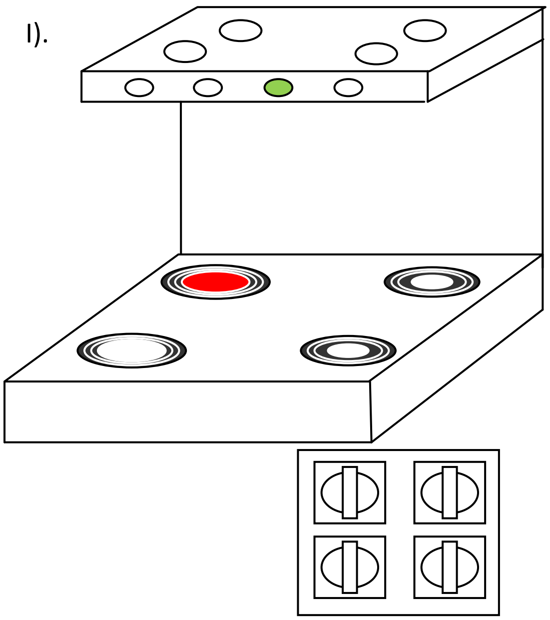
IV)



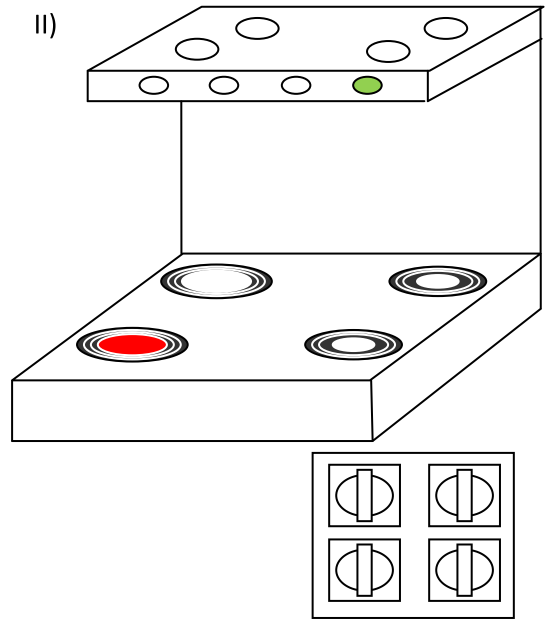
<u>Scenario Four:</u>

In this scenario, the green and red light is on. Choose which rotary knob is used to switch **off** the **RED** light. Mark your chosen rotary knob on each stove with an **X**.

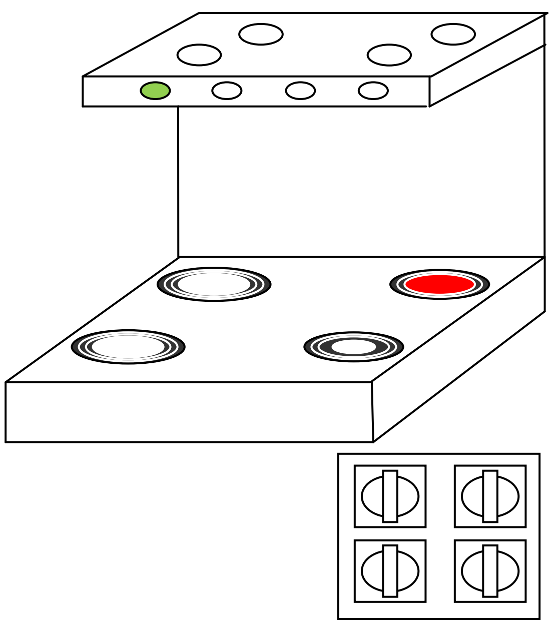
I).



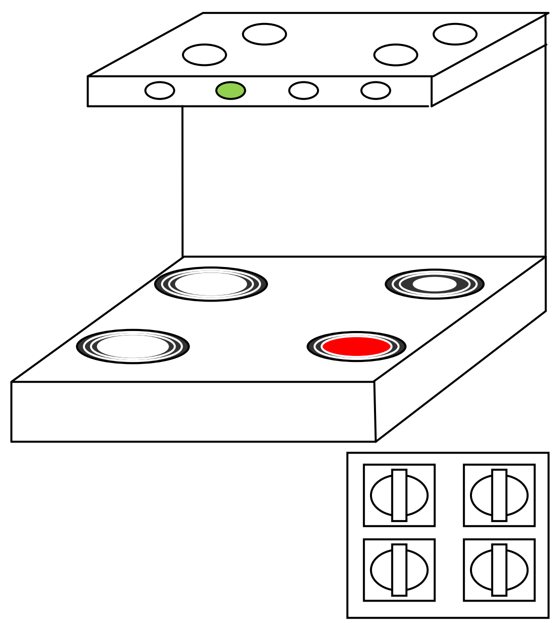
II)



III)



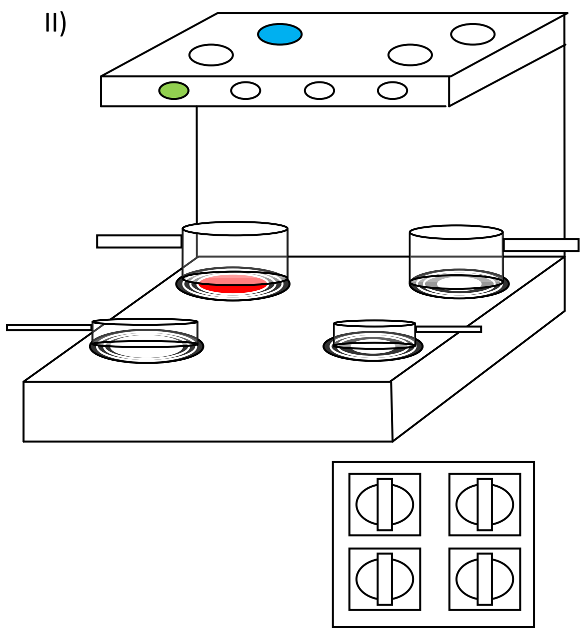
IV)



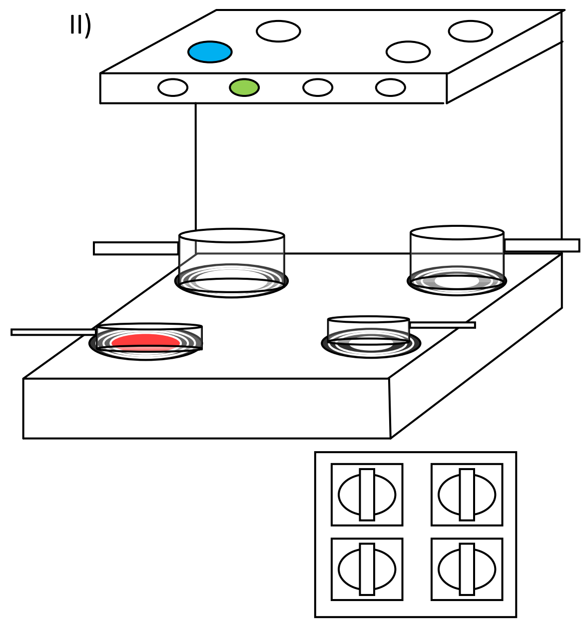
<u>Scenario Five:</u>

In this scenario, the blue light on top of the hob ring is on, followed by the red light. Then, the green light is on. Choose which rotary knob is used to switch **off** the **RED** light. Mark your chosen rotary knob on each stove with an X.

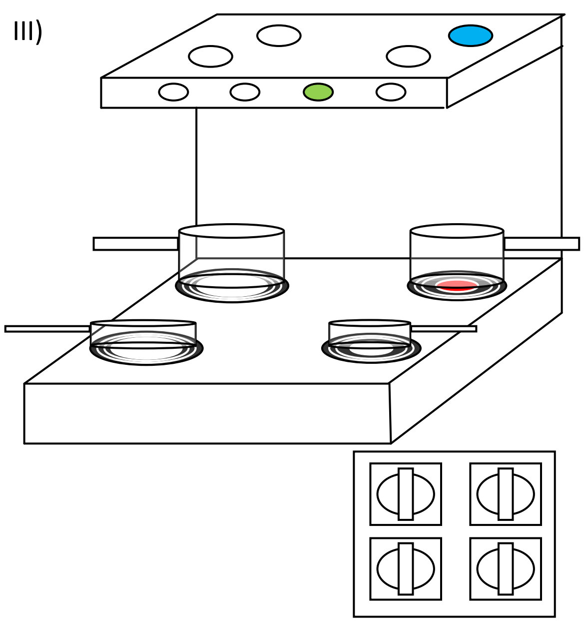
II)



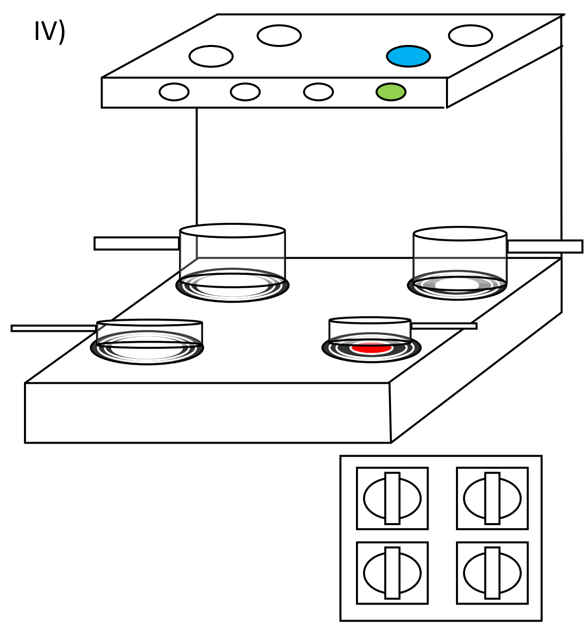
II)



III)



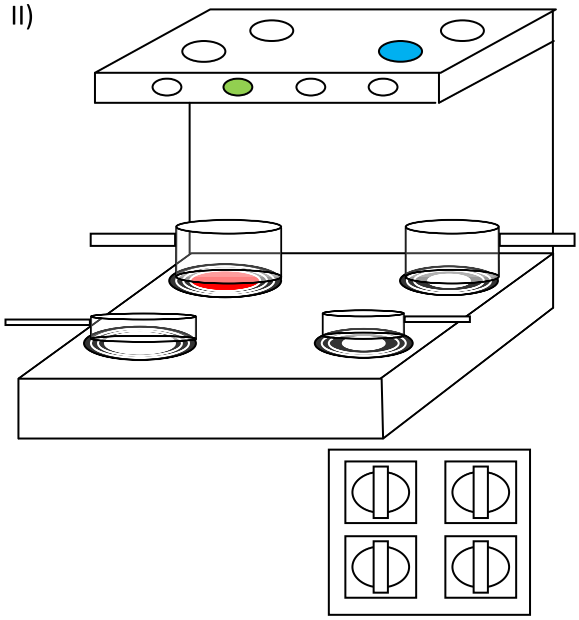
IV)



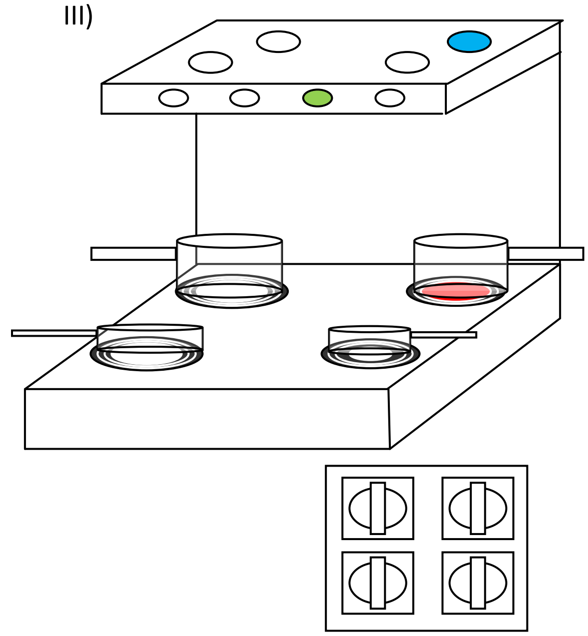
<u>Scenario Six:</u>

In this scenario, all sets of lights are on; red, green and blue. Choose which rotary knob is used to switch **off** the **RED** light. Mark your chosen rotary knob on each stove with an **X**.

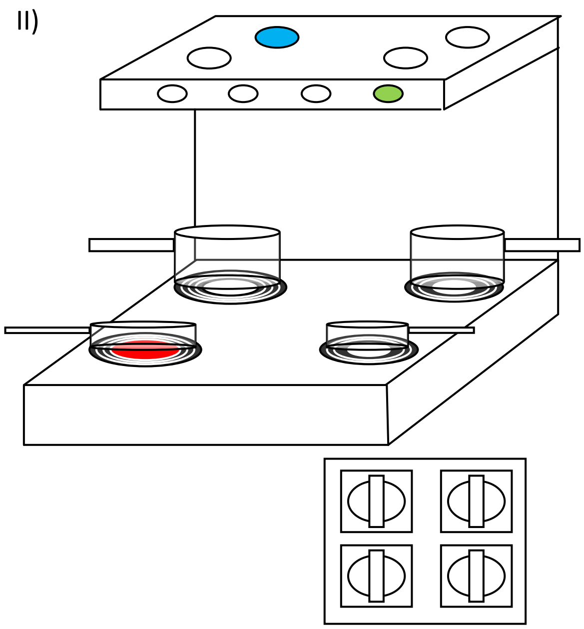
II)



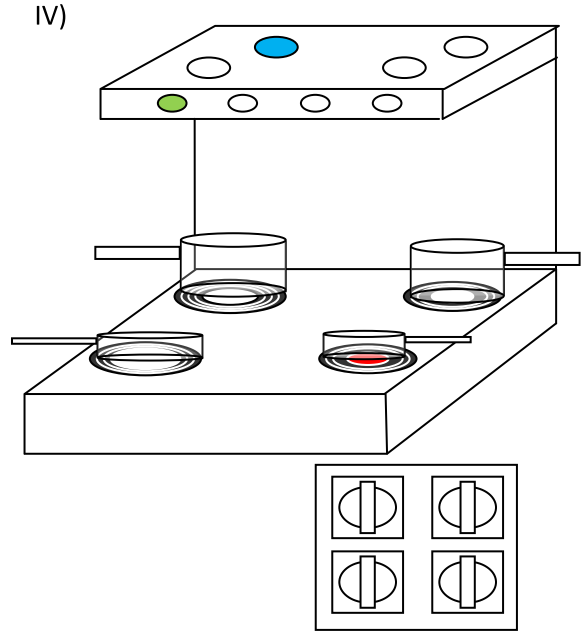
III)



II)



IV)



APPENDIX C: ANALYSIS RESULTS OF EXPERIMENT 1 (Chapter 3)

Results of Chi-Square Analysis by Likelihood Ratio and Pearson Chi-Square Results for Experiment 1 - Ambient Cueing in Cooker Controls

Linear Cooker-Control Arrangement

Scenarios	Linkages	Likelihood Ratio	Pearson Chi-Square
Red (R) LEDs	Linkage IV and II	$x^2(1) = 1.060, p = 0.303$	$x^2(1) = 1.049, p = 0.306$
	Linkage IV and III	$x^2(1) = 1.060, p = 0.303$	$x^2(1) = 1.049, p = 0.306$
	Linkage IV and V	$x^2(1) = 0.104, p = 0.747$	$x^2(1) = 0.104, p = 0.747$
	Linkage IV and VII	$x^2(1) = 5.635, p = 0.017$	$x^2(1) = 5.091, p = 0.024$
	Linkage IV and Others	$x^2(1) = 3.553, p = 0.059$	$x^2(1) = 3.388, p = 0.138$
	Linkage IV and Redundancy	$x^2(1) = 5.635, p = 0.017$	$X^2(1) = 5.091, p = 0.024$
Blue (B) LEDs	Linkage IV and II	$x^2(1) = 1.060, p = 0.303$	$x^2(1) = 1.049, p = 0.306$
	Linkage IV and III	$x^2(1) = 1.060, p = 0.303$	$x^2(1) = 1.049, p = 0.306$
	Linkage IV and V	$x^2(1) = 0.104, p = 0.747$	$x^2(1) = 0.104, p = 0.747$
	Linkage IV and VII	$x^2(1) = 5.635, p = 0.017$	$x^2(1) = 5.091, p = 0.024$
	Linkage IV and Others	$x^2(1) = 3.553, p = 0.059$	$x^2(1) = 3.388, p = 0.138$
	Linkage IV and Redundancy	$x^2(1) = 5.635, p = 0.017$	$x^2(1) = 5.091, p = 0.024$
Red – Green (CRG) LEDs	Linkage III and II	$x^2(1) = 6.068, p = 0.014$	$x^2(1) = 5.882, p = 0.015$
	Linkage III and IV	$x^2(1) = 8.123, p = 0.004$	$x^2(1) = 7.714, p = 0.005$
	Linkage III and V	$x^2(1) = 8.123, p = 0.004$	$x^2(1) = 7.714, p = 0.005$
	Linkage III and VII	$x^2(1) = 14.291, p < 0.001$	$x^2(1) = 12.578, p < 0.001$
	Linkage III and Redundancy	$x^2(1) = 10.740, p < 0.001$	$x^2(1) = 9.921, p = 0.002$
Red-Green (IRG) LEDs	Linkage IV and II	$x^2(1) = 1.060, p = 0.303$	$x^2(1) = 1.049, p = 0.306$
	Linkage IV and III	$x^2(1) = 3.553, p = 0.059$	$x^2(1) = 3.388, p = 0.066$
	Linkage IV and V	$x^2(1) = 2.046, p = 0.153$	$x^2(1) = 2.000, p = 0.157$
	Linkage IV and VII	$x^2(1) = 5.635, p = 0.017$	$x^2(1) = 5.091, p = 0.049$
	Linkage IV and XII	$x^2(1) = 104, p = 0.747$	$x^2(1) = 0.104, p = 0.747$
	Linkage IV and Redundancy	$x^2(1) = 3.553, p = 0.059$	$x^2(1) = 3.388, p = 0.066$

Red-Green-Blue (CRGB) LEDs	Linkage III and II	x^2 (1) = 9.723, p = 0.002	x^2 (1) = 9.191, p = 0.002
	Linkage III and V	x^2 (1) = 9.723, p = 0.002	x^2 (1) = 9.191, p = 0.002
	Linkage III and IV	x^2 (1) = 7.503, p = 0.006	x^2 (1) = 7.219, p = 0.007
	Linkage III and VII	x^2 (1) = 14.497, p < 0.001	x^2 (1) = 12.600, p < 0.001
	Linkage III and redundancy	x^2 (1) = 14.497, p < 0.001	x^2 (1) = 12.600, p < 0.001
Red-Green-Blue (IRGB) LEDs	Linkage V and II	x^2 (1) = 4.758, p = 0.029	x^2 (1) = 4.500, p = 0.034
	Linkage V and III	x^2 (1) = 4.758, p = 0.029	x^2 (1) = 4.500, p = 0.034
	Linkage V and IV	x^2 (1) = 0.224, p = 0.636	x^2 (1) = 0.222, p = 0.637
	Linkage V and VII	x^2 (1) = 0.224, p = 0.636	x^2 (1) = 0.222, p = 0.637
	Linkage V and IX	x^2 (1) = 7.399, p = 0.007	x^2 (1) = 6.640, p = 0.010
	Linkage V and XII	x^2 (1) = 7.399, p = 0.007	x^2 (1) = 6.640, p = 0.010
	Linkage V and XIII	x^2 (1) = 0.224, p = 0.636	x^2 (1) = 0.222, p = 0.637
	Linkage V and Others	x^2 (1) = 7.399, p = 0.007	x^2 (1) = 6.640, p = 0.010
	Linkage V and Redundancy	x^2 (1) = 7.399, p = 0.007	x^2 (1) = 6.640, p = 0.010

Quadrant Cooker Control Arrangement

Scenarios	Linkages	Likelihood Ratio	Pearson Chi-Square
Red (R) LEDs	Linkage III vs. XI	x^2 (1) = 52.520, p < 0.001	x^2 (1) = 42.320, p < 0.001
	Linkage III vs. other types	x^2 (1) = 60.837, p < 0.001	x^2 (1) = 46.154, p < 0.001
Blue (B) LEDs	Linkage III vs. XI	x^2 (1) = 42.251, p < 0.001	x^2 (1) = 35.507, p < 0.001
	Linkage III vs. R	x^2 (1) = 36.950, p < 0.001	x^2 (1) = 32.051, p < 0.001
	Linkage III vs. other types	x^2 (1) = 50.247, p < 0.001	x^2 (1) = 39.286, p < 0.001
Red-Green (CRG) LEDs	Linkage III vs. XI	x^2 (1) = 52.520, p < 0.001	x^2 (1) = 42.320, p < 0.001
	Linkage III vs. other types	x^2 (1) = 60.837, p < 0.001	x^2 (1) = 46.154, p < 0.001
Red-Green (IRG) LEDs	Linkage III vs. XI	x^2 (1) = 52.520, p < 0.001	x^2 (1) = 42.320, p < 0.001
	Linkage III vs. other types	x^2 (1) = 60.837, p < 0.001	x^2 (1) = 46.154, p < 0.001
Red-Green-Blue (CRGB) LEDs	Linkage III vs. XI	x^2 (1) = 52.520, p < 0.001	x^2 (1) = 42.320, p < 0.001
	Linkage III vs. other types	x^2 (1) = 60.837, p < 0.001	x^2 (1) = 46.154, p < 0.001
Red-Green-Blue (IRGB) LEDs	Linkage III vs. XI	x^2 (1) = 46.899, p < 0.001	x^2 (1) = 38.782, p < 0.001
	Linkage III vs. R	x^2 (1) = 46.899, p < 0.001	x^2 (1) = 38.782, p < 0.001
	Linkage III vs. other types	x^2 (1) = 55.056, p < 0.001	x^2 (1) = 42.593, p < 0.001

APPENDIX D: RESULTS AND ANALYSIS OF EXPERIMENT 2 (CHAPTER 4)

Chi-square Analysis between different linkages responds in the linear and quadrant control arrangement.

1. Linear control arrangement (Malaysian)

Scenarios		Likelihood Ratio	Pearson Chi-Square
Red (CR) LED	Linkage III vs. II, V & XI	x^2 (1) = 1.721, p = 0.190	x^2 (1) = 1.677, p = 0.195
	Linkage III vs. IV	x^2 (1) = 0.159, p = 0.690	x^2 (1) = 0.159, p = 0.690
Blue (CB) LED	Linkage III vs. II, R	x^2 (1) = 2.288, p =0.130	x^2 (1) = 2.160, p = 0.142
	Linkage III vs. IV	x^2 (1) = 0, p = 1	x^2 (1) = 0.000, p = 1
	Linkage III vs. V	x^2 (1) = 0.187, p 0.666	x^2 (1) = 0.186, p = 0.666
	Linkage III vs. XI	x^2 (1) = 0.846, p = 0.358	x^2 (1) = 0.833, p = 0.361
Red-Green (RG) LED	Linkage III vs. II, V, XI, R	x^2 (1) = 5.058, p = 0.025	x^2 (1) = 4.658, p = 0.031
	Linkage III vs. IV	x^2 (1) = 0.144, p = 0.705	x^2 (1) = 0.144, p = 0.705
Red-Green (IRG) LED	Linkage III vs. II, IV, V, XI	x^2 (1) = 0.241, p = 0.623	x^2 (1) = 0.240, p = 0.624
	Linkage III vs. VII	x^2 (1) = 1.200, p = 0.273	x^2 (1) = 1.154,p = 0.283
	Linkage III vs. XII	x^2 (1) = 0, p = 1	x^2 (1) = 0, p = 1
Red-Green-Blue (CRGB) LED	Linkage III vs. II, V, XI	x^2 (1) = 1.721, p = 0.190	x^2 (1) = 1.677, p = 0.195
	Linkage III vs. IV	x^2 (1) = 0.687, p = 0.407	x^2 (1) = 0.682, p = 0.409
	Linkage III vs. VII, R	x^2 (1) = 3.581, p = 0.058	x^2 (1) = 3.333, p = 0.068
Red-Green-Blue (IRGB) LED	Linkage III vs. V, XI, XIII, R	x^2 (1) = 0.846, p = 0.328	x^2 (1) = 0.833, p = 0.361
	Linkage III vs. VII, XII, O	x^2 (1) = 2.288,p = 0.130	x^2 (1) = 2.160, p = 0.142

2. Linear Control arrangement (British)

Scenarios		Likelihood Ratio	Pearson Chi-Square
Red (CR) LED	Linkage III vs. II	x^2 (1) = 1.721, p = 0.190	x^2 (1) = 1.677, p = 0.195
	Linkage III vs. IV	x^2 (1) = 0.687, p = 0.407	x^2 (1) = 0.682, p = 0.409
	Linkage III vs. V	x^2 (1) = 0.159, p = 0.690	x^2 (1) = 0.159, p = 0.690
	Linkage III vs. VII	x^2 (1) = 3.581, p = 0.058	x^2 (1) = 3.333, p = 0.068

Blue (CB) LED	Linkage III vs. II, V	x^2(1) = 0, p = 1	x^2(1) = 0, p = 1
	Linkage III vs. IV	x^2(1) = 0.187, p = 0.666	x^2(1) = 0.186, p = 0.666
	Linkage III vs. VII	x^2(1) = 1.200, p = 0.273	x^2(1) = 1.154, p = 0.283
Red-Green (CRG) LED	Linkage III vs. II	x^2(1) = 9.505, p = 0.002	x^2(1) = 8.889, p = 0.003
	Linkage III vs. V	x^2(1) = 6.946, p = 0.008	x^2(1) = 6.652, p = 0.010
Red-Green (IRG) LED	Linkage III vs. II	x^2(1) = 0, p = 1	x^2(1) = 0, p = 1
	Linkage III vs. IV, VII, XI	x^2 (1) = 0.377, p = 0.539	x^2(1) = 0.370, p = 0.543
	Linkage III vs. V	x^2(1) = 0.846, p = 0.358	x^2(1) = 0.833, p = 0.361
	Linkage III vs. XII	x^2(1) = 0.241, p = 0.623	x^2(1) = 0.240, p = 0.624
Red-Green-Blue (CRGB) LED	Linkage III vs. II, V	x^2(1) = 0, p = 1	x^2(1) = 0, p = 1
	Linkage III vs. VII, R	x^2(1) = 1.200, p = 0.273	x^2(1) = 1.154, p = 0.283
Red-Green-Blue (IRGB) LED	Linkage III vs. V, XIII, R	x^2(1) = 0.846, p = 0.328	x^2(1) = 0.833, p = 0.361
	Linkage III vs. VII, O	x^2(1) = 2.288,p = 0.130	x^2(1) = 2.160, p = 0.142

3. Quadrant Control Arrangement (Malaysian)

Scenarios		Likelihood Ratio	Pearson Chi-Square
Red (CR) LED	Linkage III vs. II, IV...etc.	x^2(1) = 41.589, p < 0.001	x^2(1) = 30.000, p < 0.001
Blue (CB) LED	Linkage III vs. II	x^2(1) = 22.327, p < 0.001	x^2(1) = 19.286, p < 0.001
	Linkage III vs. IV, V, VI...etc.	x^2(1) = 29.274, p < 0.001	x^2(1) = 22.941, p < 0.001
Red-Green (CRG) LED	Linkage III vs. Redundancy	x^2(1) = 18.028, p < 0.001	x^2(1) = 16.133, p < 0.001
	Linkage III vs. II, IV, V, VI...etc.	x^2(1) = 29.274, p < 0.001	x^2(1) = 22.941, p < 0.001
Red-Green (IRG) LED	Linkage III vs. Redundancy	x^2(1) = 18.028,p < 0.001	x^2(1) = 16.133, p < 0.001
	Linkage III vs. II, IV, V...etc.	x^2(1) = 29.274, p < 0.001	x^2(1) = 29.274, p < 0.001
Red-Green-Blue (CRGB) LED	Linkage III vs. II, VII, R	x^2(1) = 18.694, p < 0.001	x^2(1) = 16.425, p < 0.001
Red-Green-Blue (IRGB) LED	Linkage III vs. IV	x^2(1) = 18.694, p < 0.001	x^2(1) = 16.425, p < 0.001
	Linkage III vs. R	x^2(1) = 14.663, p < 0.001	x^2(1) = 13.393, p < 0.001

4. Quadrant Control Arrangement (British)

Scenarios		Likelihood Ratio	Pearson Chi-Square
Red (CR) LED	Linkage III vs. II, IV...etc.	x^2 (1) = 41.589, p < 0.001	x^2 (1) = 30.000, p < 0.001
Blue (CB) LED	Linkage III vs. Others	x^2 (1) = 22.327, p < 0.001	x^2 (1) = 19.286, p < 0.001
	Linkage III vs. Redundancy	x^2 (1) = 22.327, p < 0.001	x^2 (1) = 19.286, p < 0.001
	Linkage III vs. II, IV... etc.	x^2 (1) = 29.274, p < 0.001	x^2 (1) = 22.941, p < 0.001
Red-Green (CRG) LED	Linkage III vs. II, IV, V...etc.	x^2 (1) = 41.589, p < 0.001	x^2 (1) = 30.000, p < 0.001
Red-Green (IRG) LED	Linkage III vs. II, IV, V...etc.	x^2 (1) = 41.589,p < 0.001	x^2 (1) = 30.000, p < 0.001
Red-Green-Blue (CRGB) LED	Linkage III vs. VII	x^2 (1) = 26.893, p < 0.001	x^2 (1) = 22.533, p < 0.001
Red-Green-Blue (IRGB) LED	Linkage III vs. R	x^2 (1) = 26.893, p < 0.001	x^2 (1) = 22.533, p < 0.001

Chi-square Analysis of Cross-Cultures on responds to Linkage III between Malaysian and British.

1. **Linear Cooker Control Arrangements**

Scenarios	Linkages	Likelihood Ratio	Pearson Chi-Square
Red (CR) LED	Linkage III to others	x^2 (1) = 0.000, p = 1.000	x^2 (1) = 0.000, p = 1.000
Blue (CB) LED	Linkage III to others	x^2 (1) = 0.187, p = 0.666	x^2 (1) = 0.186, p = 0.666
Red-Green (CRG) LED	Linkage III to others	x^2 (1) = 2.170, p = 0.141	x^2 (1) = 2.143, p = 0.143
Red-Green (IRG) LED	Linkage III to others	x^2 (1) = 0.241, p = 0.623	x^2 (1) = 0.240, p = 0.624
Red-Green-Blue (CRGB) LED	Linkage III to others	x^2 (1) = 0.687, p = 0.407	x^2 (1) = 0.682, p = 0.409
Red-Green-Blue (IRGB) LED	Linkage III to others	x^2 (1) = 0.000, p = 1.000	x^2 (1) = 0.000, p = 1.000

2. **Quadrant Cooker Control Arrangements**

Scenarios	Linkages	Likelihood Ratio	Pearson Chi-Square
Red (CR) LED	Linkage III to others	-	-
Blue (CB) LED	Linkage III to others	-	-
Red-Green (CRG) LED	Linkage III to others	x^2 (1) = 1.421, p = 0.233	x^2 (1) = 1.034, p = 0.309
Red-Green (IRG) LED	Linkage III to others	x^2 (1) = 2.916, p = 0.088	x^2 (1) = 2.143, p = 0.143
Red-Green-Blue (CRGB) LED	Linkage III to others	x^2 (1) = 1.200, p = 0.273	x^2 (1) = 1.154, p = 0.283
Red-Green-Blue (IRGB) LED	Linkage III to others	x^2 (1) = 1.200, p = 0.273	x^2 (1) = 1.154, p = 0.283

APPENDIX E:ANALYSIS RESULTS OF EXPERIMENT 3 COOKER CONTROL COMPATIBLITY WITH AMBIENT STOVE BETWEEN MALAYSIAN AND BRITISH (CHAPTER 5)

1. Number of Attempts

Levene's Test of Equality of Error Variance		F (11, 372) = 4.170, p < 0.001.
Between Subjects Effects		
Compatibility		F (1, 372) = 641.67, p < 0.001
Condition		F (5, 372) = 45.11, p < 0.001
Compatibility * Condition		F (5, 372) = 50.94, p < 0.001
Post Hoc Test (LSD)		
Red	Blue	p = 0.045
	Green	p < 0.001
	RedGreen	p < 0.001
	RedBlue	p < 0.001
	RedGreenBlue	p < 0.001
Blue	Red	p = 0.045
	Green	p > 0.05
	RedGreen	p < 0.001
	RedBlue	p < 0.001
	RedGreenBlue	p < 0.001
Green	Red	p < 0.001
	Blue	p > 0.05
	RedGreen	p < 0.001
	RedBlue	p < 0.001

	RedGreenBlue	$p < 0.001$
RedGreen	Red	$p < 0.001$
	Blue	$p < 0.001$
	Green	$p < 0.001$
	RedBlue	$p > 0.05$
	RedGreenBlue	$p < 0.001$
RedBlue	Red	$p < 0.001$
	Blue	$p < 0.001$
	Green	$p < 0.001$
	RedGreen	$p > 0.05$
	RedGreenBlue	$p < 0.001$
RedGreenBlue	Red	$p < 0.001$
	Blue	$p < 0.001$
	Green	$p < 0.001$
	RedGreen	$p < 0.001$
	RedBlue	$p = 0.001$

T-Test number of attempts between compatible and incompatible scenarios.

	Compatible	
Incompatible	Red Scenario	$t(31) = 3.963, p < 0.001$
	Blue Scenario	$t(31) = 6.106, p < 0.001$
	Green Scenario	$t(31) = 2.963, p = 0.006$
	Red-Green Scenario	$t(31) = 13.083, p < 0.001$
	Red--Blue Scenario	$t(31) = 15.960, p < 0.001$
	Red-Green-Blue Scenario	$t(31) = 22.369, p < 0.001$

T-Test number of attempts in the single LEDs in the compatible and incompatible scenarios.

Compatible LEDs	
Red vs. Blue scenario	t (31) = 2.467, p = 0.019
Red vs. Green scenario	t (31) = 2.708, p = 0.011
Green vs. Blue scenario	T (31) = 0.641, p = 0.526

Incompatible LEDs	
Red vs. Blue scenario	t (31) = 3.392, p = 0.002
Red vs. Green scenario	t (31) = 1.709, p = 0.097
Green vs. Blue scenario	t (31) = 1.887, p = 0.069

T-Test numbers of attempts as number of LEDs increase from 1 to 2 or 3 LEDs both in the compatible and incompatible arrangements.

Compatible LEDs	
Red to Red-Green scenario	t (31) = 2.483, p = 0.0019
Red to Red-Blue scenario	t (31) = 1.969, p = 0.058
Red to Red-Green-Blue scenario	t (31) = 2.210, p = 0.035
Blue to Red-Blue scenario	t (31) = 0.120, p =0.905
Blue to Red-Green-Blue	t (31) = 0.346, p = 0.731
Green to Red-Green	t (31) = 0.00, p = 1.00
Green to Red-Green-Blue	t (31) = 0.392, p 0.698
Red-Green to Red-Green-Blue	t (31) = 0.432, p = 0.669
Red-Blue to Red-Green-Blue	t (31) = 0.661, p = 0.514

Incompatible LEDs	
Red to Red-Green scenario	t (31) = 8.685, p < 0.001
Red to Red-Blue scenario	t (31) = 7.965, p < 0.001

Red to Red-Green-Blue scenario	t (31) = 13.577, p < 0.001
Blue to Red-Blue scenario	t (31) = 9.735, p < 0.001
Blue to Red-Green-Blue	t (31) = 18.166, p < 0.001
Green to Red-Green	t (31) = 9.792, p < 0.001
Green to Red-Green-Blue	t (31) = 7.166, p < 0.001
Red-Green to Red-Green-Blue	t (31) = 6.330, p < 0.001
Red-Blue to Red-Green-Blue	t (31) = 7.464, p < 0.001

2. **Initial Response Times**

Levene's Test of Equality of Error Variance		F (11, 372) = 2.7970, p = 0.002
Between Subjects Effects		
Compatibility		F (1, 372) = 38.92, p < 0.001
Condition		F (5, 372) = 3.089, p = 0.01
Compatibility * Condition		F (5, 372) = 2.078, p = 0.068
Post Hoc Test (LSD)		
Red	Blue	p = 0.449
	Green	p = 0.161
	RedGreen	p = 0.882
	RedBlue	p = 0.079
	RedGreenBlue	p = 0.054
Blue	Red	p = 0.449
	Green	p = 0.031
	RedGreen	p = 0.543
	RedBlue	p = 0.315.
	RedGreenBlue	p = 0.239

Green	Red	p = 0.161
	Blue	p = 0.031
	RedGreen	p = 0.121
	RedBlue	p = 0.002
	RedGreenBlue	p = 0.001
RedGreen	Red	p = 0.882
	Blue	p = 0.543
	Green	p = 0.121
	RedBlue	p = 0.107
	RedGreenBlue	p = 0.075
RedBlue	Red	p = 0.079
	Blue	p = 0.315
	Green	p = 0.002
	RedGreen	p = 0.107
	RedGreenBlue	p = 0.863
RedGreenBlue	Red	p = 0.054
	Blue	p = 0.239
	Green	p = 0.001
	RedGreen	p = 0.075
	RedBlue	p = 0.863

T-Test initial response times between compatible and incompatible scenarios.

	Compatible	
Incompatible	Red Scenario	t (31) = 1.502, p = 0.143
	Blue Scenario	t (31) = 1.912, p = 0.065
	Green Scenario	t (31) = 7.675, p < 0.001
	Red-Green Scenario	t (31) = 5.872, p < 0.001
	Red--Blue Scenario	t (31) = 4.191, p < 0.001
	Red-Green-Blue Scenario	T (31) = 5.380, p < 0.001

T-test initial response times as number of LEDs increase from 1 to 2 to 3 LEDs both in the compatible and incompatible LED arrangements.

Compatible LEDs	
Red to Red-Green	t(31) = 1.496, p = 0.145
Red to Red-Blue	t(31) = 0.284, p = 0.778
Red to Red-Green-Blue	t(31) = 0.846, p = 0.404
Blue to Red-Blue	t(31) = 0.670, p = 0.508
Blue to Red-Green-Blue	n.s
Green to Red-Green	t(31) = 3.059, p = 0.005
Green to Red-Green-Blue	n.s
Red-Green to Red-Green-Blue	t(31) = 0.383, p = 0.704
Red-Blue to Red-Green-Blue	t(31) = 1.342, p = 0.189
Incompatible LEDs	
Red to Red-Green	t (31) = 2.637, p = 0.013
Red to Red-Blue	t (31) = 3.366, p = 0.002
Red to Red-Green-Blue	t (31) = 4.010, p < 0.001
Blue to Red-Blue	t (31) = 3.580, p = 0.001
Blue to Red-Green-Blue	t (31) = 3.457, p = 0.002

Green to Red-Green	t (31) = 2.652, p = 0.0013
Green to Red-Green-Blue	t (31) = 4.638, p < 0.001
Red-Green to Red-Green-Blue	t (31) = 3.753, p = 0.001
Red-Blue to Red-Green-Blue	t (31) = 1.208, p = 0.236

T-test of initial response times between single LEDs only in both compatible and incompatible LEDs arrangement.

Compatible LEDs arrangement	
Red to Blue	t (31) = 0.560, p = 0.580
Red to Green	t (31) = 3.135, p = 0.004
Green to Blue	t (31) = 4.456, p < 0.001

Incompatible LEDs arrangement	
Red to Blue	t (31) = 1.532, p = 0.136
Red to Green	t (31) = 0.879, p = 0.386
Green to Blue	t (31) = 2.249, p = 0.032

3. **Correct Response Times**

Levene's Test of Equality of Error Variance		F (11, 372) = 4.07670, p < 0.002
Between Subjects Effects		
Compatibility		F (1, 372) = 98.98, p < 0.001
Condition		F (5, 372) = 4.429, p = 0.01
Compatibility * Condition		F (5, 372) = 3.84, p = 0.002
Post Hoc Test (LSD)		
Red	Blue	p = 0.740

	Green	$p = 0.01$
	RedGreen	$p = 0.975$
	RedBlue	$p = 0.113$
	RedGreenBlue	$p = 0.189$
Blue	Red	$p = 0.740$
	Green	$p = 0.024$
	RedGreen	$p = 0.717$
	RedBlue	$p = 0.056$
	RedGreenBlue	$p = 0.100$
Green	Red	$p = 0.010$
	Blue	$p = 0.024$
	RedGreen	$p = 0.009$
	RedBlue	$p < 0.001$
	RedGreenBlue	$p < 0.001$
RedGreen	Red	$p = 0.975$
	Blue	$p = 0.717$
	Green	$p = 0.009$
	RedBlue	$p = 0.120$
	RedGreenBlue	$p = 0.200$
RedBlue	Red	$p = 0.113$
	Blue	$p = 0.056$
	Green	$p < 0.001$
	RedGreen	$p = 0.120$
	RedGreenBlue	$p = 0.786$
RedGreenBlue	Red	$p = 0.189$
	Blue	$p = 0.100$

	Green	$p < 0.001$
	RedGreen	$p = 0.200$
	RedBlue	$p = 0.789$

T-Test correct response times between compatible and incompatible scenarios.

	Compatible	
Incompatible	Red Scenario	$t(31) = 2.966, p = 0.006$
	Blue Scenario	$t(31) = 4.783, p < 0.001$
	Green Scenario	$t(31) = 3.727, p = 0.001$
	Red-Green Scenario	$t(31) = 6.065, p < 0.001$
	Red-Blue Scenario	$t(31) = 6.848, p < 0.001$
	Red-Green-Blue Scenario	$t(31) = 5.980, p < 0.001$

T-test corrected response times as number of LEDs increase from 1 to 2 to 3 LEDs both in the compatible and incompatible LED arrangements.

Compatible LEDs	
Red to Red-Green	$t(31) = 2.825, p = 0.008$
Red to Red-Blue	$t(31) = 1.253, p = 0.220$
Red to Red-Green-Blue	$t(31) = 1.943, p = 0.061$
Blue to Red-Blue	$t(31) = 0.734, p = 0.468$
Blue to Red-Green-Blue	
Green to Red-Green	$t(31) = 2.590, p = 0.014$
Green to Red-Green-Blue	$t(31) = 2.132, p = 0.041$
Red-Green to Red-Green-Blue	$t(31) = 0.599, p = 0.554$
Red-Blue to Red-Green-Blue	$t(31) = 1.528, p = 0.137$

Incompatible LEDs	
Red to Red-Green	t (31) = 2.049, p = 0.049
Red to Red-Blue	t (31) = 3.396, p = 0.002
Red to Red-Green-Blue	t (31) = 3.004, p = 0.005
Blue to Red-Blue	t (31) = 5.417, p < 0.001
Blue to Red-Green-Blue	t (31) = 3.287, p = 0.003
Green to Red-Green	t (31) = 4.321, p < 0.001
Green to Red-Green-Blue	t (31) = 4.300, p < 0.001
Red-Green to Red-Green-Blue	t (31) = 3.105, p = 0.004
Red-Blue to Red-Green-Blue	t (31) = 1.314, p = 0.0198

T-test of corrected response times between single LEDs only in both compatible and incompatible LEDs arrangement.

Compatible LEDs arrangement	
Red to Blue	t (31) = 1.076, p = 0.290
Red to Green	t (31) = 3.650, p = 0.001
Green to Blue	t (31) = 3.659, p = 0.001

Incompatible LEDs arrangement	
Red to Blue	t (31) = 0.102, p = 0.919
Red to Green	t (31) = 4.304, p < 0.001
Green to Blue	t (31) = 3.011, p = 0.005

APPENDIX F:
TASK DESCRIPTION BY STEPS

Prepare Curry Paste:

i. Add and blend these ingredient to very fine
   a. Red Chillies
   b. Ginger
   c. Red Onions
   d. Shrimp
   e. Garlic
   f. Shallots
   g. Water
ii. Then, add these dry ingredients and blend together
   a. Galangal
   b. Candlenuts
   c. Turmeric Powder
iii. Blend all ingredients to make a paste and add in a bowl

Prepare Cook Fish:

i. Add cooking oil in a saucepan
ii. Add these herbs and spices in the saucepan
   a. Cloves
   b. Star Anise
   c. Cardamon
   d. Halba

    e. Cinnamon
    f. Curry leaves
iii. Stir herbs and spices until aromatic
iv. Add curry paste
v. Stir curry paste until thin layer of il rises on toop
vi. Add coconut milk
vii. Add fish
viii. Add seasoning ingredients
    a. Sugar
    b. Salt
    c. Tamarind
ix. Add tomatoes
x. Stir and simmer for 3 minutes

Prepare Chicken

i. Cut chicken breast into 2in x 1in cubes then add in a bowl
ii. Add and mix wet ingredients with chicken cubes
    a. Oysters sauce
    b. Fish sauce
    c. Sesame oil
    d. Soy sauce
iii. Blend these dry ingredients, then add and mix with the chicken cubes
    a. Ginger
    b. Lemongrass
    c. Galangal
    d. Red chilies
iv. Add seasoning ingredients
    a. Sugar

   b. Sesame seeds
   c. White pepper

v. Marinate for 1 hour

Cook Chicken

i. Cut pandan leaves into 30cm long
ii. Wash and dry pandan leaves
iii. Take chicken cubes, warp the chicken with pandan leaves. Then tight it.
iv. Add cooking oil in a saucepan
v. Add chicken wrap in wok
vi. Then, fry until golden brown

APPENDIX G:
ANALYSIS RESULTS OF EXPERIMENT 4:
AMBIENT DISPLAY IN THE DIGITAL KITCHEN ENVIRONMENT (CHAPTER 6)

COMPLETION TIMES

1. Contrast completion times of cooking tasks compared to *curryPaste* task.

Cooking Tasks	Contrast
Cook Chicken	$F(1, 18) = 17.508$, $p = 0.001$
Prepare Chicken	$F(1, 18) = 0.024$, $p = 0.879$
Cook Fish	$F(1,18) = 12.894$, $p = 0.002$

2. Contrast completion times across interaction interfaces and expertise when compared to ambient interface.

Interaction Interface	Contrast
Recipe Book	$F(1, 18) = 0.410$, $p = 0.530$
Smart Chalk	$F(1, 18) = 20.180$, $p < 0.001$

3. Contrast completion times across cooking task and expertise when compared to *curryPaste* task.

Cooking Tasks	Contrast
Cook Chicken	F (1,18) = 2.218, p = 0.154
Prepare Chicken	F (1,18) =7.976, p = 0.011
Cook Fish	F (1,18) = 0.016, p = 0.900

4. Contrast completion times across cooking task and interaction interface.

Interaction Interface	Cooking Tasks	Contrast
smartChalk vs. Ambient	Cook chicken vs. Curry paste	F (1,18) = 0.650, p = 0.431
	Prepare chicken vs. Curry paste	F (1,18) = 0.749, p = 0.398
	Cook fish vs. Curry paste	F (1,18) = 0.930, p = 0.348
recipeBook vs. Ambient	Cook chicken vs. Curry Paste	F (1,18) = 4.856, p = 0.041
	Prepare chicken vs. Curry paste	F (1,18) = 2.968, p = 0.102
	Cook fish vs. Curry paste	F (1,18) = 1.226, p = 0.283

5. T-Test of completion cooking times for Malaysian

Interaction Interface	T-Test Results
recipeBook vs. ambient	T (39) = 1.910, p = 0.063
Ambient vs. smartChalk	T (39) = 7.496, p < 0.001
smartChalk vs. recipeBook	T (39) = 7.496, p < 0.001

6. T-Test of completion cooking times for Non-Malaysian

Interaction Interface	T-Test Results
recipeBook vs. ambient	T (39) = 2.270, p = 0.029
Ambient vs. smartChalk	T (39) = 0.245, p = 0.808
smartChalk vs. recipeBook	T (39) = 1.857, p = 0.071

7. T-Test of completion cooking times for both Malaysian and Non-Malaysian

Interaction Interface	T-Test Results
recipeBook	T (74.61) = 3.019, p = 0.003
Ambient	T (66.52) = 2.987, p = 0.004
smartChalk	T (78) = 0.594, p = 0.554

NUMBER OF STEPS COMPLETED

1. Contrast percentage number of steps completed compared to *curryPaste* task

Cooking Tasks	Contrast
Cook Chicken	F (1, 18) = 0.001, p = 0.970
Prepare Chicken	F (1, 18) = 5.315, p = 0.033
Cook Fish	F (1, 18) = 0.066, p = 0.800

2. Contrast percentage number of steps completed across interaction interfaces and expertise when compared to ambient interface

Interaction Interface	Contrast
Recipe Book	F (1,18) = 9.612, p = 0.006
Smart Chalk	F (1,18) = 0.532, p = 0.475

3. Contrast percentage number of steps completed across interaction interfaces and cooking tasks.

Interaction Interface	Cooking Tasks	Contrast
smartChalk vs. Ambient	Cook chicken vs. Curry paste	F (1, 18) = 1.308. p = 0.268
	Prepare chicken vs. Curry paste	F (1,18) = 0.697, p = 0.415
	Cook fish vs. Curry paste	F (1,18) = 0.165, p = 0.689
recipeBook vs. Ambient	Cook chicken vs. Curry Paste	F (1,18) = 15.786, p = 0.001
	Prepare chicken vs. Curry paste	F (1,18) = 2.342, p = 0.143
	Cook fish vs. Curry paste	F (1,18) = 3.027, p = 0.099

4. T-Test on percentage number of steps completed among Malaysia participants.

Interaction Interface	T-Test Results
recipeBook vs. ambient	T (39) = 1.038, p = 0.308
Ambient vs. smartChalk	T (39) = 9.722, p < 0.001
smartChalk vs. recipeBook	T (39) = 9.038, p < 0.001

5. T-Test on percentage number of steps completed among Non-Malaysian participants.

Interaction Interface	T-Test Results
recipeBook vs. ambient	T (39) = 1.606, p = 0.116
Ambient vs. smartChalk	T (39) = 4.067, p < 0.001
smartChalk vs. recipeBook	T (39) = 2.673, p = 0.011

NUMBER OF ERRROS

1. Results of chi-square test for total number of errors between Malaysian and Non-Malaysian in the cooking task for different interaction interface.

Task	Recipe	Ambient	Chalk
Curry Paste	x^2 (1) = 5.616, p = 0.018	x^2 (1) = 1.993, p = 0.158	x^2 (1) = 0.040, p 0.841
Cook Fish	x^2 (1) =1.505, p = 0.220	x^2 (1) = 20.463, p < 0.001	x^2 (1) = 6.559, p = 0.010
Prepare Chicken	x^2 (1) = 9.674, p = 0.002	x^2 (1) = 11.619, p = 0.001	x^2 (1) = 3.419, p = 0.064
Cook Chicken	x^2 (1) = 0.085, p = 0.771	x^2 (1) = 0.216, p = 0.642	x^2 (1) = 9.044, p = 0.003

Task	**Malaysian**	**Non-Malaysian**
Curry Paste	x^2 (2) = 20.983, $p < 0.001$	x^2 (2) = 8.932, $p = 0.011$
Cook fish	x^2 (2) = 25.257, $p < 0.001$	x^2 (2) = 23.617, $p < 0.001$
Prepare Chicken	x^2 (2) = 72.805, $p < 0.001$	x^2 (2) = 8.501, $p = 0.014$
Cook Chicken	x^2 (2) = 86.799, $p < 0.001$	x^2 (2) = 37.345, $p < 0.001$

APPENDIX H:
ANALYSIS RESULTS OF EXPERIMENT 5:
SYSTEM MALFUNTION IN DIGITAL KITCHEN ENVIRONMENT (CHAPTER 7)

COMPLETION TIMES

1. Contrast completion times of cooking tasks compared to *curryPaste* task.

Cooking Tasks	Contrast
Cook Chicken	$F(1, 18) = 17.508, p = 0.001$
Prepare Chicken	$F(1, 18) = 0.024, p = 0.879$
Cook Fish	$F(1,18) = 12.894, p = 0.002$

2. Contrast completion times across interaction interfaces and expertise when compared to ambient interface.

Interaction Interface	Contrast
Recipe Book	$F(1, 18) = 0.410, p = 0.530$
Smart Chalk	$F(1, 18) = 20.180, p < 0.001$

3. Contrast completion times across cooking task and expertise when compared to *curryPaste* task.

Cooking Tasks	Contrast
Cook Chicken	F (1,18) = 2.218, p = 0.154
Prepare Chicken	F (1,18) =7.976, p = 0.011
Cook Fish	F (1,18) = 0.016, p = 0.900

4. Contrast completion times across cooking task and interaction interface.

Interaction Interface	Cooking Tasks	Contrast
smartChalk vs. Ambient	Cook chicken vs. Curry paste	F (1,18) = 0.650, p = 0.431
	Prepare chicken vs. Curry paste	F (1,18) = 0.749, p = 0.398
	Cook fish vs. Curry paste	F (1,18) = 0.930, p = 0.348
recipeBook vs. Ambient	Cook chicken vs. Curry Paste	F (1,18) = 4.856, p = 0.041
	Prepare chicken vs. Curry paste	F (1,18) = 2.968, p = 0.102
	Cook fish vs. Curry paste	F (1,18) = 1.226, p = 0.283

5. T-Test of completion cooking times for Malaysian

Interaction Interface	T-Test Results
recipeBook vs. ambient	T (39) = 1.910, p = 0.063
Ambient vs. smartChalk	T (39) = 7.496, p < 0.001
smartChalk vs. recipeBook	T (39) = 7.496, p < 0.001

6. T-Test of completion cooking times for Non-Malaysian

Interaction Interface	T-Test Results
recipeBook vs. ambient	T (39) = 2.270, p = 0.029
Ambient vs. smartChalk	T (39) = 0.245, p = 0.808
smartChalk vs. recipeBook	T (39) = 1.857, p = 0.071

7. T-Test of completion cooking times for both Malaysian and Non-Malaysian

Interaction Interface	T-Test Results
recipeBook	T (74.61) = 3.019, p = 0.003
Ambient	T (66.52) = 2.987, p = 0.004
smartChalk	T (78) = 0.594, p = 0.554

NUMBER OF STEPS COMPLETED

1. Contrast percentage number of steps completed compared to *curryPaste* task

Cooking Tasks	Contrast
Cook Chicken	F (1, 18) = 0.001, p = 0.970
Prepare Chicken	F (1, 18) = 5.315, p = 0.033
Cook Fish	F (1, 18) = 0.066, p = 0.800

2. Contrast percentage number of steps completed across interaction interfaces and expertise when compared to ambient interface

Interaction Interface	Contrast
Recipe Book	F (1,18) = 9.612, p = 0.006
Smart Chalk	F (1,18) = 0.532, p = 0.475

3. Contrast percentage number of steps completed across interaction interfaces and cooking tasks.

Interaction Interface	Cooking Tasks	Contrast
smartChalk vs. Ambient	Cook chicken vs. Curry paste	F (1, 18) = 1.308. p = 0.268
	Prepare chicken vs. Curry paste	F (1,18) = 0.697, p = 0.415
	Cook fish vs. Curry paste	F (1,18) = 0.165, p = 0.689
recipeBook vs. Ambient	Cook chicken vs. Curry Paste	F (1,18) = 15.786, p = 0.001
	Prepare chicken vs. Curry paste	F (1,18) = 2.342, p = 0.143
	Cook fish vs. Curry paste	F (1,18) = 3.027, p = 0.099

4. T-Test on percentage number of steps completed among Malaysia participants.

Interaction Interface	T-Test Results
recipeBook vs. ambient	T (39) = 1.038, p = 0.308
Ambient vs. smartChalk	T (39) = 9.722, p < 0.001
smartChalk vs. recipeBook	T (39) = 9.038, p < 0.001

5. T-Test on percentage number of steps completed among Non-Malaysian participants.

Interaction Interface	T-Test Results
recipeBook vs. ambient	T (39) = 1.606, p = 0.116
Ambient vs. smartChalk	T (39) = 4.067, p < 0.001
smartChalk vs. recipeBook	T (39) = 2.673, p = 0.011

NUMBER OF ERRROS

1. Results of chi-square test for total number of errors between Malaysian and Non-Malaysian in the cooking task for different interaction interface.

Task	Recipe	Ambient	Chalk
Curry Paste	x^2 (1) = 5.616, p = 0.018	x^2 (1) = 1.993, p = 0.158	x^2 (1) = 0.040, p 0.841
Cook Fish	x^2 (1) =1.505, p = 0.220	x^2 (1) = 20.463, p < 0.001	x^2 (1) = 6.559, p = 0.010
Prepare Chicken	x^2 (1) = 9.674, p = 0.002	x^2 (1) = 11.619, p = 0.001	x^2 (1) = 3.419, p = 0.064
Cook Chicken	x^2 (1) = 0.085, p = 0.771	x^2 (1) = 0.216, p = 0.642	x^2 (1) = 9.044, p = 0.003

Task	**Malaysian**	**Non-Malaysian**
Curry Paste	x^2 (2) = 20.983, $p < 0.001$	x^2 (2) = 8.932, $p = 0.011$
Cook fish	x^2 (2) = 25.257, $p < 0.001$	x^2 (2) = 23.617, $p < 0.001$
Prepare Chicken	x^2 (2) = 72.805, $p < 0.001$	x^2 (2) = 8.501, $p = 0.014$
Cook Chicken	x^2 (2) = 86.799, $p < 0.001$	x^2 (2) = 37.345, $p < 0.001$

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