Cooking by Design
Applying Cognitive Ergonomic Guidelines

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INTRODUCTION

> A young couple is having some friends over for dinner. They are making salad, noodles, Eggplant Parmesan and garlic bread. The woman is doing most of the preparation, using the top of their electric stove, while occasionally trying to instruct her boyfriend on the technique of cooking eggplant. He lays the garlic bread out on a pan and sticks it in the oven to toast on the broil setting. He checks it about ten minutes later, and switches the knob full left. Then he goes back to the conversation with friends. His girlfriend, at the stove, is under the impression that the oven is off. Ten minutes later the meal is ready and she opens the oven. Smoke drifts out from the now charred and inedible bread.

Using an Electric Stove

The above story is an example of a **cooking error**: an error in the execution of the cooking process. It is possible that the design of the equipment used in this case, **an electric stove**, contributed to the error that occurred. This paper will examine the task of cooking and the design of the stove, and discuss how the interaction between task and tool may cause such cognitive errors. Cognitive errors are errors in information processing and decision making. It will then make suggestions about how cognitive ergonomic guidelines could be applied to improve the compatibility between the task of cooking and the stove used to accomplish it, to reduce errors, improve safety, and possibly make cooking easier along the way.

Cooking error: There are many levels of cooking error. Some errors only reduce food quality from perfect to something less than perfect. Those are difficult to quantify. But in most cases the state of food being burnt is unintended and irreversible, so burning food can be positively identified as an error. Burning utensils, pans or other non-food items would be another type of error associated with cooking on a stove. Burning oneself or starting a fire would be the most extreme example of that sort of error. The scope of this paper will be limited to cooking errors that involve the time period and temperature level of cooking. However, it should be kept in mind that there are many other parts of the cooking process, such as ingredient choice and treatment, that provide opportunities for error and also increase the overall mental workload of the cook.

For young and inexperienced cooks, cooking errors can set back the learning process. A success would lead the learner toward greater confidence and improve the chances of success in the future (Wickens, 1992). Error leads to less willingness to attempt the task, especially when it occurs in an embarrassing situation such as hosting company.

For older people, cooking can be a difficult part of everyday life. As they age, people often experience a decrease in working memory (Wickens, 1992). They need working memory in order to sustain awareness of the state of their food and the state of the stove (Endsley, 1995). In a focus group study of fifty-nine older adults (above 65 years of age), food preparation was the fifth most commonly listed daily task that had become difficult to accomplish once they got older. A typical error description involved burning pots. The researchers identified working memory as the locus of the problem (Rogers, 1998).

If we can reduce cooking errors by redesigning the stove, we might increase the number of people who successfully learn how to cook. Improvements that reduce the load on working memory by taking over cognitive tasks such as scheduling and tracking and by providing displays that require less interpretation to be useful could make cooking easier and more enjoyable and improve the quality of life for older people. Improvements that are applicable to the lives of older people may also have positive effects for younger generations.

Safety: In one type of cooking error the item that is cooked was not intended to be cooked at all! If something flammable is placed on a hot burner, a fire could start that endangers the building and the people in it. And, if someone touches a burner or oven coil directly, they could get burned. While people are generally aware that stoves are dangerous, there is evidence that their level of caution is based on whether or not they think the stove is on or expected to be hot. This context-based expectation may start at a very young age. In a 1989 study of five- to seven-year-old children , Karen Pfeffer found that while children consistently identified a cooker (some sort of stove) to be a source of danger, "seven-year-olds more often gave provisional answers than the younger children.; that is, [a child] will get burned *if* the cooker is switched on, *if* the water is hot, ..etc. (p. 312)" She also found that children consistently underestimated the extremity of the danger. Not one child in the sixty-eight studied responded that a serious injury might be the result of interaction with a cooker (Pfeffer, 1989).

This information suggests that an effective, safe stove design should clearly indicate when the stove is on and when the coils and burners are hot. The state of the stove should be apparent to onlookers and latecomers as well as the person using the appliance.

TASK ANALYSIS

An Electric Stove

To anticipate errors such as the ones that occurred in the story, this paper will analyze the use of the electric stove that was actually involved. While other stoves may not experience the drawbacks of this one, the application of cognitive ergonomic guidelines regarding the cooking task interface should be as relevant to any other stove design.

Description: The stove is a well-used Beaumark, perhaps twenty years old, with four burners and an oven. The burners are arranged, two large, two small, in an alternating pattern so that one large one is in the back left corner of the stove top and the other large one is in the front right corner. The controls are all on a vertical panel at the back of the stove. Like all electric stoves, the coils are heated based on the thermal characteristics of a resistor that current is flowing through. The temperature varies according to how constantly (or inconstantly) the current is applied. For higher temperatures, the coils are on almost all the time. It takes a while for them to heat up, and a while for them to cool down. When they are very hot they glow red, but at lower temperatures they remain dark.

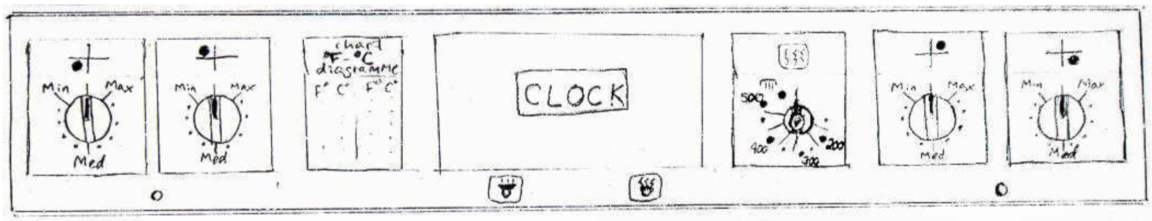


Fig. 1 The control panel of an electric stove.

Displays and controls: There are five dials and four indicator lights {see fig. 1}. The four burner control knobs turn counter-clockwise from off to high. A graphic above each burner control indicates which burner it relates to. The indicator light centered under the left burner controls shines orange if either one of the left burners is turned on. The indicator light centered under the right burner controls shines if either of the right burners is turned on.

The oven control turns clockwise from off to 500 degrees Fahrenheit. When the oven control is turned fully in the clockwise direction the oven switches from bake mode to broil mode. After that switch, the knob may be turned back counter-clockwise to turn down the temperature (still on broil). The indicator lights for Broil and Bake are under the clock, in line with the burner indicators; they have icons superimposed on the glass in front of them to distinguish them from one another. If the oven is set to Bake, both the light on the left and the light on the right turn on when the coils are turned on (when the oven is below target temperature and the oven is therefore heating). When the oven is set to broil, only the left light turns on, while the top coil is heating.

Stovetop Cooking

There has been a fair amount of research done on the most appropriate left-right ordering of stove controls (Payne, 1995). Other aspects of the display and control system also deserve attention.

Four burners: As described before, the stove has two burners fore and aft. These burners are solid coils raised slightly from the stovetop. When in use, they are usually completely covered by some type of pan. However, they are still visible from the side (if one were to lean or bend down to view them from the level of the stovetop). Due to the larger sizes of two of the burners, they are actually centered slightly closer to the middle of the stovetop {see fig. 2}.

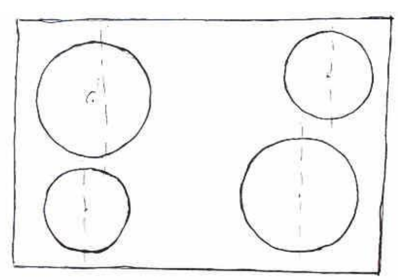


Fig. 2 The stovetop burner arrangement.

Four controls: There is one control for each burner. Though the burners do have unique positions in the left-right dimension, the controls don't follow that ordering. They are in the optimal order for a stove in which the burners do not have unique left-right positions (Payne, 1995), but the graphics above each control may reduce the effect of this natural ordering. That is, given a graphic to translate, the operator may choose to process the graphic rather than remember or relate to the order of the controls. Since this graphic requires that the operator mentally abstract the stove top into a grid, this may increase the load on working memory - if it is not given sufficient resources the process of identifying the control / burner relationship may fail and thus lead to errors.

Another aspect of the stovetop controls that could lead to errors is the similarity between the 'off' position and the 'Med' heat position. The global shapes of these two settings are more or less the same. Which way the dial is pointing is indicated with a red mark on one half of the dial handle. In low light conditions the eye may not be able to discriminate between red and other dark colors (Wickens, 1992). Altogether these characteristics could lead to mistakes in which the operator thinks a burner is off or on medium when the opposite case is true.

Two lights: There are two indicator lights related to the controls. Though they do indicate that something on a particular side of the stove is on, they do not help discriminate between the two burners most likely to be confused (the front-back pairs). Also, when the front burner is on and the back burner on the same side is turned on, there is no visible indication (other than the setting of the control itself) of the change in state. That could lead to errors in which a burner is turned on but not in use, a situation that can often lead to an object (wooden spoon, plastic spice bottle…) or a person being burned.

Furthermore, while the dials and indicator lights indicate the settings for the burners, they do not indicate the state of the burners themselves. When you turn a burner on it is not immediately the temperature at which it is set. The operator must wait until the burner or pan is hot before proceeding, yet another variable to track and extrapolate. Impatient operators may set a burner to 'Max' to get it to heat up faster, thereby increasing the chances that an item intended to cook on a lower heat gets overcooked or burnt. On the other hand, when the controls and indicators are all off, this does not insure that the burners are not dangerously hot. They take time to cool. The rear right burner is also the vent for the oven, so this burner may get hot even if the stove was never in use. With their expectancy of danger lowered because all visible indicators say the stove is off, people may place hands or dishes on hot burners by mistake. This delayed reaction is also in effect for any intermediate change in burner setting. That means that the operator must base control actions on the future temperature of the burner. People are generally poor at prediction and extrapolation (Wickens, 1992), so this could lead to errors also.

A note on training: People who grew up using gas stoves were trained with the opposite pattern of system state visibility and control / burner reaction. When you turn a gas stove up, the flame rises visibly and the burner heat increases almost instantly. When you turn it off, you can see there is no flame and there is also no heat under your pan. Further research might be in order to explore how this affects performance on an electric stove and what kind of remedial training could best improve transferability of gas stove experience to electric stove use.

Using the Oven

The oven may be used instead of the stove or in conjunction with stove cooking. There is a window in the oven door and a light that can be turned on to illuminate the interior of the oven. A rack in the oven can be moved to vary the relative position of a pan with respect to one of the heating coils. There is a heating coil on the top of the oven, used for broiling, and a heating coil on the bottom, used in conjunction with the one on top for baking and roasting.

Baking: To bake something, you set the rack height, preheat the oven to a certain temperature, and then put the food in the oven for a certain amount of time. To preheat the oven, you turn the oven control clockwise to a certain temperature. This is the opposite direction from that which is associated with an increase in heat in the stove controls. While the indicators make it fairly clear to the operator which way to turn the knob, the direction of motion might be confused when perceived by someone else in the area. In our original example, the woman using the stove thought that her partner had turned the oven off. That error might have been caused by this inconsistency of motion between stove and oven controls.

While the direction of increase is easily perceivable from the display, the precise temperature setting is not. Radiating lines create a sense of scale but do not themselves point to the major divisions of the scale. They point to the 25- and 75-degree values, while large dots and text labels indicate 100-degree increments and smaller dots indicate 50 degrees, 150 degrees, etc. Once again, the operator must translate an abstraction and then make a decision based on that abstraction. This situation might contribute to slips. Slips are errors where the operator has correct awareness of the situation, and devises a correct intention to act, but errs during the execution of the action (Wickens, 1992).

When you turn the oven control on, both the oven indicator lights come on. They will stay on until the oven is hot. Once the oven is pre-heated, the indicator lights turn off. This is your signal to put the food in. The lights will turn on and off intermittently as the coils are turned on to maintain the set temperature. Opening and closing the oven door will alter the interior temperature. The controls and displays do indicate the precise state of the oven, but only what the setting is and whether or not the oven is at that setting. They would fail to indicate whether or not the oven temperature is above the current control setting: if you turn the oven down, there is no display predicting how long it will take to cool to that temperature. You can only wait and see when the coils turn on again, meaning the oven has cooled to below the control setting. This could lead to mistakes such as overcooking an item by leaving it in a hot oven.

If the oven is at the set level and remains undisturbed, there may be no special indication that the oven is on. This situation could contribute to errors such as forgetting there is something in the oven. It's possible that a signal that represents just whether or not the oven is turned on would have prevented the charred toast.

Finally, the indicator lights for the oven are not located adjacent to the oven controls. The icons superimposed on them are not very visible in dark conditions; the lights look like round orange lights, identical to the ones that indicate stove use. This may lead to confusion or lack of association: even when the lights are perceived, their meaning may not be understood.

Broiling: There is an icon for the broiler over the indicator light for the top coil, and yet another icon for broil above the maximum setting on the oven control {see fig. 3}. To set the oven to broil, you turn the knob fully clockwise, then counter-clockwise to reduce the temperature. This is neither obvious nor intuitive. The icons representing broil and bake are not accompanied by any text. Their meanings may not be clear. The global shapes of the icons are very similar, so there is low discriminability between them (Wickens, 1992).

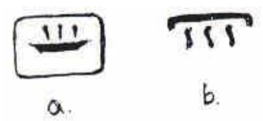


Fig. 3 Broiler icons: a) over the indicator light; b) on the control panel.

The location of the broil indicator light to the left of the bake indicator light is not compatible with the physical system they represent. The physical relation between the coils being controlled is top to bottom. This disparity between representation of the system and system structure might lead the operator to compose an incorrect mental model of the system. If the operator already has a correct mental model of the system, the display is incompatible with it and may be ignored or incorrectly translated.

Burning: There are no constraints on how much you can burn objects in the oven or on the stove. There is no way to set such constraints or even to set alarms to inform you that something is burning. The smell or sight of smoke is often the cook's first sign that something is wrong. When food is in the oven, it is closed off from the kitchen so the operator is less likely to smell it burning. Some recipes involve blackening food, so setting a universal limit (so that all ovens turn off if their contents are burning) would displease operators who intend to char their food. The absence of any constraint makes major errors possible.

The Cooking Environment

Environmental factors can make any of these signals harder to perceive. If people in the kitchen are smoking cigarettes the smell of burnt food may be indistinguishable from the general odor. Tall containers or the handles of implements might cover or obscure parts of the display panel.

Conversations, children, or other things to monitor might divert attention from the cooking task and increase the load on working memory. Important or potentially critical guests could increase the stress level of the situation, causing the operator to make decisions faster and with less accuracy (Wickens, 1992). All of these factors might contribute to errors.

Cooking a Meal

Typically a meal involves more than one dish. While the operator may use a timer to count down the time taken for one dish at a time, generally a cook keeps track of multiple cooking times and progress with a mental model of the whole cooking situation.

The cook makes repeated comparisons between the clock time and memory of both the required cooking time and the time that cooking began. Process assessments also include regular checks on the 'doneness' of the dish itself. At each check, both time and doneness evaluations require mathematical calculations. After the current situation is assessed, the cook will then extrapolate from current trends to determine when the situation should be changed or checked again in the future. Like all cognitive tasks requiring sustained attention resources and working memory, this task is susceptible to interruptions and distractions (Wickens, 1992). Forgetfulness may require the operator to refer to an authority (a person or recipe) to be reminded of optimal cooking time and temperature. A number of dishes may require alterations in temperature (example: "bring to boil then reduce heat and simmer for twenty minutes") over the course of the cooking process. Some alterations are based purely on time, while others depend on the status of the food (example: "simmer until sauce thickens").

This process is highly susceptible to error due to the high level of mental workload. The workload can be somewhat reduced by training; if the cook knows the recipe well enough to have it stored in long term memory, the load on working memory is reduced. This is especially useful in stressful situations, since working memory resources can be more limited under stress (Wickens, 1992). In any case, working memory requires attention resources, and information stored in working memory will degrade over time. Waiting for dishes to complete cooking is a type of vigilance task. Performance on it will start to deteriorate after half an hour (Wickens, 1992). Regular reassessment of when multiple dishes are predicted to complete involves a heavy mental workload:

> Prediction of future states.. imposes a heavy load on working memory by requiring the maintenance of present conditions, future conditions, rules used to generate the latter from the former, and actions that are appropriate to future conditions (Payne, 1995).

When starting a meal preparation task, an operator should begin by scheduling the cooking times of various dishes in order that all are done in time to be served together. Preferably completion times are close enough together that all hot food is still hot and nothing is overcooked. This requires prediction and calculation of a set of variables (scheduling) and is another possible source of error in the cooking process.

GUIDELINES FOR IMPROVEMENT

The following guidelines are taken from a set collected by students in a Cognitive Ergonomics class at the University of Waterloo in 1998. Most of them are based on information in Wickens' 1992 textbook, Engineering Psychology and Human Performance.

Perception

The first stage of situation awareness is perception (Endsley, 1995).

Minimize perceptual confusion: When possible, controls and displays should be adjacent to one another, with a one-to-one mapping between controls and displays.

The burner controls should each be associated with one indicator light. Connections between controls and burners can be made clear by drawing a line from the control to the burner {see Wickens, p. 326}. Burner positions in the Left-Right dimension should either be eliminated or taken into account when positioning controls.

The oven controls and displays should be given a distinct space on the control panel. The complexity of electronics and number of fuses the manufacturer is willing to include in the machine may limit the number of lights that can be included in the display. However, it seems that adding two lights should be reasonable.

Use color to provide a pre-attentive organizing structure: right now the control knobs each have an square with rounded corners drawn in orange around them. Using different boundary colors for stove controls vs oven controls or front vs back burner controls could help organize the display. There is a limit to this in that you want to avoid cluttering up the display or using colors that have no meaning. It might be interesting to do research that explores whether there are particular colors that are most naturally associated with foreground and background or that work well to distinguish oven from stovetop controls.

Provide icons and symbols whose global shape provides easy discrimination: If icons are to distinguish between broil and bake, they should be given discriminable global shapes. This should increase understanding and perception of their different meanings. In the case of this stove, the round shape of the light is the dominating part of the image when the room is dark; the overlaid icon is imperceptible. A better masking technique would make the icons themselves light up, further distinguishing the indicators from the round stove indicator lights.

Also, the globally similar 'Med' and 'off' settings in the stove top controls could be made distinguishable by marking the pointing tip of the control knob and the 'off' position on the control panel so that there is an emergent feature when the one points to the other. For example, you could put a semi-circle on the tip of the knob and a complimentary semi-circle on the panel so that when the control is off they form a circle.

Since global processing tends to be pre-attentive and automatic, this aspect of design can reduce attention demands on the operator (Wickens, 1992).

Use consistent representations: There are two issues addressed by this guideline: motion and icon use. The direction of motion indicating increase in temperature should be consistently applied in all the controls. There should also be a consistent iconic representation of the broil setting, instead of the two different icons on the current display.

Reinforce the meaning of symbols with accompanying text labels: In case consistent, discriminable oven icons still fail to express their intended association, their meaning should be reinforced with text labels, such as BROIL and BAKE. The temperature indicators on the oven control dial should also employ more text (numerical) indicators in addition to (or instead of) the confusing abstract representation currently in use. There is enough room on the dial to include more numbers, but the limitation of space would dictate how many divisions to label. Since the size of a dot is not commonly encountered as an indication of the significance of a scalar variable, perhaps a more familiar format could be translated with more automaticity and less error. A straight ruler, for example, uses longer thicker lines to indicate units and smaller lines to indicate subdivisions of those units. That display format could be applied to the oven control knob. Further research could determine the clearest design for this display.

Use the presence (rather than absence) of a signal to indicate something the operator needs to know: The operator of an electric oven needs to know when the oven is heated to the desired temperature. Presently that is indicated by the absence of an oven indicator light. The presence of a signal should be used to indicate this state.

Mental Model

The mental model is the basis for understanding a system (Wickens, 1992).

Design systems so that the execution of action and the system response are visible: In a number of cases the execution of an action could be made more visible.

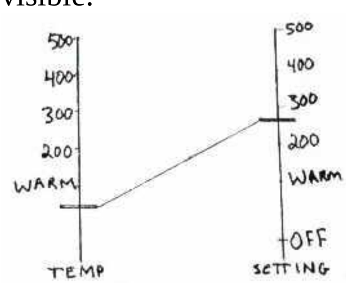


Fig. 4 An alternative display where the slope indicates the direction of temperature change

If the oven is already hot and someone turns it down or off there is no change in the light display. There is also no indication of the gradual decrease in oven temperature that follows the change in setting. In order to indicate both these things there should be separate displays indicating the setting and the current state of the oven. An especially effective display might connect the two so that the direction of change is also indicated {see fig. 4}. This would clearly indicate when someone makes a drastic change in setting, since the slope of the line will be steep. This could prevent errors where one operator turns something off and another operator continues to think it is on.

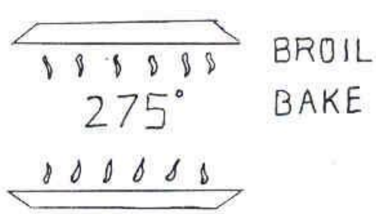
While a display of this sort might be very useful, the meaning of it may not be transparent, so the introduction of it may require more training for the operator. Research is recommended to determine the ease with which a novice user learns to interpret a display like this.

Provide feedback that indicates the true status of the equipment: With current technology it is possible to provide direct, visible feedback about the temperature of a stove burner. A light or temperature-sensitive strip in the frame around the burner could indicate temperature by color, intensity, or size. The referent of a display so directly congruent to a particular burner could not be mistaken. The advantage of a temperature-sensitive material is that it would indicate temperature even after the stove has been turned off. It would also indicate temperature when the stove was never on, as in the case where a burner is heated by vented heat from the oven. You could also achieve that effect with a light or tier of lights which are triggered by a certain temperature setting; whatever is deemed to be significantly above room temperature may be a good minimum trigger temperature.

Again, the increased complexity of additional displays would make stove units harder and more costly to manufacture. They might also make them less reliable. If the displays are not trustworthy their usefulness is questionable. Further research could explore the best technical solution. A cost-benefit analysis would then determine whether or not the public ever got to see it incorporated. That analysis, in turn, would be illuminated by research into the actual reduction of errors (especially injuries and damaging accidents) enjoyed by people operating with the benefit of this temperature feedback.

A graduated display around the burner would provide the same kind of control / burner feedback experienced with a gas stove. This alone, however, wouldn't provide direct correlation between operation of a gas stove and operation of an electric stove. There would still be a time delay between control and response that is not experienced in a gas stove.

Information should be presented in way that is compatible with the operator's mental model: A correct mental model of the physical oven represents the broiling function with a hot coil on the top of the oven, with directional heat coming down on the food from above. The representation of baking involves both top and bottom coils and heat from both directions. Information presented on the display panel should reflect these representations.



Rather than side by side, perhaps the Broil and Bake indicators should be aligned vertically {see fig. 5}. This could prevent errors in which the operator is mistaken as to the mode of the oven, such as might be created by confusion regarding the meaning of the bake and broil icons.

Fig. 5 Proposed oven display.

When the operator must read a precise value, use a digital display: The current oven temperature could be displayed digitally {see fig. 5}. This might be more difficult than it sounds. Technical limitations determine the feasibility of adding this feature. Generally, baking is an imprecise science, so the displaying the precise value may be overkill. However, a large digital display may be easier to read at a distance than a point on a dial. It might also be more clearly understood (Wickens, 1992). This could improve the tendency to correct errors in setting since the operator could compare the displayed temperature directly to the number they have in memory. Research could explore the ability of operators to detect an undesirable temperature given a digital display or a dial to indicate the value.

Working Memory

Working memory constitutes the bottleneck for situation awareness (Fracker, 1987, as cited by Payne, 1995).

Reduce the possibility of errors by using constraints: It may be possible to build constraints into an electric stove such that it will not burn pans or food. Or, it could inform you when something was burning. Such constraints or alarms will be ineffective if they are not accurate. If they are triggered too easily they will become annoying and interfere with the process they are supposed to aid. Audible alarms should be minimized so that if one goes off it is clear what the presence of an alarm indicates. And, the signal must be strong enough to be detected in the midst of environmental factors such as those described earlier. If there are constraints such that the oven turns off if something in it is burning, this action should be indicated to the operator. Since unimportant things sometimes spill onto the bottom of an oven or burner and char, the design specifications for what should be detected as burning enough to trigger the constraint must be chosen carefully.

Minimize the amount of information the operator must maintain or transform in working memory: Cooking using an electric stove currently depends heavily on assessment, prediction and scheduling done by the operator. Recipes give the total cooking time required. Figuring out how much cooking time is left requires a transformation of information about what time cooking began combined with total cooking time and what time is it now. Some of this load could be taken off the operator with computer assistance. That could help prevent overcooking or burning.

Computer assistance has some advantages over mechanical timers: a mechanical timer indicates only how much time is left until the timer goes off. The timer does not know what it is timing, whether the food will be done or need to be turned down, etc, when its alarm goes off, or what. It has only one kind of alarm or bell sound that it can execute. A computer program could keep track of many variables at once.

In fact, microwave ovens incorporate this kind of digital technology. In a user-based evaluation study in 1993, Sandhu recommended use of microwaves over electric cookers for elderly users because "electric cookers … require more extensive and exhaustive data collection" (p. 31). Some microwaves have defrost programs which will run a certain time, give a particular alarm to indicate food should be turned over, and then resume until done, indicating doneness with a recognizable chime. Even the simplest microwaves incorporate a timing mechanism in the microwave control.

An electric stove could be equipped with these abilities, and more. Devices which require pushing buttons and reading digital displays can be hard to learn how to operate, especially for older users (Rogers, 1998). Speech recognition software has advanced to the point where telling an automatic speech recognition system instructions for how to cook something can be done with fairly natural language, almost as easily as you would instruct a person assisting you (Brems, 1995). A combination of a computer timing program and an ASR system could control an electric stove while being easy for the novice user to master. Such a program might prompt the operator for a name for the food being cooked. Thus when the food is done it could inform the operator with a verbal message that includes which food is done. This would also enable natural interaction during the cooking process; for example, the operator could ask the stove how much longer the beans will take to cook.

It is obviously beyond the scope of this paper to suggest all the parameters of such a system. Design and implementation may be too costly at the moment. But demand from our aging population may instigate the development of this functionality in the near future. It could reduce working memory load and therefore errors that involve forgetfulness or distraction. A precise understanding of the usability of this type of application requires exploration in future studies.

Provide technology aids to assist in extrapolation of future trends: Machines are better at scheduling than people (Wickens, 1992). A computer program could take inputs of cooking requirements for different dishes and output a recommended schedule by which all the food will get cooked by a certain time. It could also inform you when transfer times have arrived. This product could be sold as an additional module for an electric stove, or as an independent item. User trust might be a limitation, however, since if the user doesn't trust the system they won't use it.

We've discussed the time delay inherent in the electric stove control process. A technology aid could be used to make this delay visible; to allow the operator to preview the future state of the equipment. Stairmasters and similar exercise equipment provide this kind of preview to their operators. As the equipment speed increases, a flashing line indicating your current position proceeds along a visual display of the program. The operator can see what the level is, what it was, and when they will reach the next level of intensity. An electric stove could offer this kind of display to preview the temperature level of a burner or of the oven. Preview can reduce the errors induced by a time delay (Wickens, 1992).

CONCLUSION

Findings

The Task Analysis of cooking with an electric stove revealed a number of ways in which the stove design could contribute to errors. Controls and displays do not clearly indicate the action necessary to alter the state of a particular part of the stove. Actions do not consistently lead to a visible system response. Control motions are not consistently mapped to phenomena. The stove displays reflect the settings of the controls but not the state of the burners while some of the oven displays reflect the state of the oven but not the setting of the control. Displays are shared by some controls while other displays are far away from the settings they indicate. Some of the indicators are confusing or indistinguishable from one another, and the whole process imposes a heavy load on working memory by requiring prediction, maintenance of process instructions, calculations and transformations of values, as well as a lot of tracking of information on multiple objects.

Recommendations

The design guidelines recommended above can reduce error by improving operator perception, contributing to a correct mental model of the system, and reducing load on working memory.

Limitations

A number of these guidelines involve advanced or complex technology. Application of them may be costly or reduce the reliability of the equipment. Cookers are currently expected to be operational for more than 10 years. People use them nearly every day, so they must be robust. Furthermore, some of this technology has never been applied to this type of task. That's not to say it couldn't be, but that further research is necessary to determine the technical specifications and abilities such technology could offer. Kitchen appliances that can talk to you have been predicted since the 1950's. It will be interesting to see if society invests in using speech technology in this application.

Adding signals and indicators could confuse the user by making the visual field more complex. Numerous lights might make it hard for the user to detect a particular light. Still, improvements in the specificity of indicators should result in a reduction of error.

Further Research

Further research could explore issues such as cost, technical feasibility, reliability, usability, and user trust. Each of these issues has been raised regarding at least one of the recommended design guidelines. Perhaps more importantly, research could determine whether application of these guidelines actually improves ease of use and reduces errors in electric stove cooking. Some of them might make cooking easier for the novice or for a person who was originally trained to use a gas stove, while others might require more training to use effectively. Specific research directions have been suggested in conjunction with specific guidelines in the body of the paper.

We've hypothesized that providing indications that the stove is hot as well as indicators that it is on will improve user safety by triggering context-sensitive caution. The effectiveness of the particular design recommendations toward improving user detection of a dangerous situation and the resultant safety [subsequent actions chosen by users] would be worthy subjects of further study.