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Menu hierarchies for in-vehicle user-interfaces: Modelling the depth vs. breadth trade-off

Gary E. Burnett [a,*], Glyn Lawson [a], Richard Donkor [a], Yukiyo Kuriyagawa [b]

[a] Human Factors Research Group, Faculty of Engineering, University of Nottingham, Nottingham NG7 2RD, UK
[b] Department of Mechanical Engineering, College of Industrial Technology, Nihon University, Japan

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ABSTRACT

Menus are commonly employed within user-interfaces, but are not necessarily a suitable solution for emerging new contexts. For instance, for in-vehicle displays, the use of visually oriented menus creates a clear distraction burden. To investigate how the visual demand of menus varied as a function of their breadth, depth and structure, a study was conducted following the ISO occlusion protocol. Participants were asked to find and select target words on a touchscreen by navigating menus of varying breadths and depths (16×3; 8×4; 4×6; 12×2) when options were arranged either in alphabetical order (structured menus) or randomly (unstructured menus). Tasks were achieved either with full vision or whilst wearing occlusion goggles enabling only brief (1.5 s) opportunities to visually access the touchscreen. Preliminary equations were derived from the data indicating fundamentally different relationships for the visual demand of an interface dependent on whether anticipation can be used during the task. For structured menus, the visual demand was a logarithmic function of the breadth of the menus, whereas for unstructured menus, the relationship was quadratic. Moreover, results indicated that for structured menus breadth was favoured over depth, as the lowest visual demand was associated with 16×3 menu hierarchies. Conversely, for unstructured menus, compromise hierarchies (e.g. 4×6; 8×4) were associated with the least visual demand. Conclusions are drawn regarding the setting of boundary (acceptable/unacceptable) conditions for alternative menu structures for use within vehicles.

1. Introduction

1.1. Menus in user-interface design

Menus are ubiquitous within contemporary user-interfaces forming a key part of the WIMP (Windows, Icons, Menus, Pointing) direct-manipulation philosophy [1]. Menus rely on a user's increased ability for "recognition rather than recall", and subsequently provide clear benefits in usability over command-based interface styles [2].

A key design issue for menus concerns the depth vs. breadth trade-off within a hierarchical tree structure. Designers will commonly need to decide whether to emphasise breadth (number of options on individual screens) or depth (number of screens to navigate through) in an interface solution. Researchers recognised the significance of this issue early in the development of graphical user-interfaces and several key studies were conducted in the 1980s and 1990s (e.g. [3–5]). In fact, this topic has continued to retain the interest of researchers (e.g. [6]).

The present work places an emphasis on two studies that span the period of research activity. The first, reported by Landauer and Nachbar [7], investigated the time required to locate and select (acquire) targets on a touchscreen within menus of varying depths and breadths. Their paper has subsequently been cited over 100 times and appears in several key textbooks (e.g. [1]) forming the basis for the overall recommendation that breadth is favoured over depth when considering user performance for different menu hierarchies. For instance, the time to acquire a target within a 16×3 menu (16 options/screen; 3 screens to navigate through) would be predicted to be quicker than the time to select an equivalent target in a 2×12 menu.

The second study is reported by Cockburn and Gutwin [6]. They collected their own data and compared it with that of Landauer and Nachbar [7] and others and concluded that the degree to which a user can anticipate where a target is located within options on a screen has a significant effect on results. Such anticipation may arise, either as a result of structure in the layout of options (as was the case for the Laundauer and Nachbar study) or due to a user's familiarity with an interface. In the current paper, the term structured refers to menus in which selectable items are arranged with alphabetical order; unstructured refers to menus which are arranged in a random fashion.

* Corresponding author. Tel.: +44 (0)115 95 14030; fax: +44 (0)115 84 66771.
E-mail address: gary.burnett@nottingham.ac.uk (G.E. Burnett).

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The research studies of Laundauer and Nachbar [7] and Cockwin and Gutwin [6] themselves build upon the findings of Hick [8] and Hyman [9] who investigated the relationship between the time taken to react to a stimulus based on the amount of information presented in that stimulus. Their work is often expressed as the Hick–Hyman law presenting a logarithmic relationship between reaction time and the number of choices available. It was postulated that such a logarithmic rule exists because people subdivide the total number of options into categories, eliminating about half of the remaining choices at each step. However, this sub-dividing strategy can only occur when users are able to anticipate where a target stimulus exists within the range of options [6]. In situations where users have to consider each option one at a time, the relationship between response time and the number of choices has been found to be linear [6]. Landauer and Nachbar (p. 76) refer to this as "a sequential visual scan-and-evaluate" strategy [7].

1.2. Menus beyond the desktop

The WIMP philosophy arose for GUIs in which users carried out tasks using a keyboard, pointing device (typically a mouse) and accompanying visual display. In particular, the suitability of a WIMP-style interface for a given task assumes fundamentally that users are wholly engaged in the activity. The ubiquity of modern user-interfaces has ensured that such notions are no longer valid. User-interfaces now exist in a range of contexts where divided attention is required, for instance, using a mobile phone while walking [10] or using a vehicle navigation system while driving [11]. In these situations, interface designers have to consider the interactions between tasks of varying priorities placing different demands on a user's mental and physical resources.

For driving, the visual demand of the user-interface is particularly important. Research has shown that visual distraction has considerable negative effects on driving safety, related to the lateral control of the vehicle and response to emerging hazards [12]. In the complex, safety–critical driving situation, it is essential that user-interfaces do not place unacceptable levels of demand on the driver. Distraction and lack of attention are widely recognised to be considerable contributory factors in current vehicle crashes (e.g. [13]).

In-vehicle user-interfaces increasingly employ menus as a flexible, intuitive means of enabling drivers (and passengers) to access functionality. In particular, this has been the case as the range of functionality on offer within vehicles has escalated and designers have sought ways of allowing users to interact with new information and services within the space-restricted vehicle environment [14]. The previous empirical and modelling research noted above concerning menu design has been conducted in conditions where a user has full vision available to navigate a menu to acquire a target. Under conditions where visual access to menus is time-limited (as is the case with driving), it is unclear whether the fundamental relationships observed in previous research exist to the same degree or even in the same form.

This paper describes a study based largely on the aforementioned experiments by Landauer and Nachbar [7] and Cockburn and Gutwin [6]. The overall aim was to identify recommendations for depth vs. breadth for in-vehicle user-interface menu hierarchies.

2. Methodology

A range of methods exist for assessing the safety-related impacts of in-vehicle user-interfaces (e.g. lane-change task, peripheral detection, occlusion). As noted by Burnett [14], methods vary according to the environment in which they operate (road, test track, simulator, laboratory, etc.), the task manipulations that arise (multiple task, single task loading, no tasks given, etc.) and the measures taken (driving performance, secondary performance, opinions, etc.). Despite considerable research and standards activities in this area, there is no universally agreed upon method for use by researchers and practitioners [12]. Each method has its own advantages and disadvantages from different perspectives (validity, reliability, sensitivity, economy, usability, etc.).

The current paper utilises the Occlusion protocol as an example of a laboratory-based method in which single task loading is provided and measures are taken related to in-vehicle user-interface visual demand. An international standard [15] exists which describes the method in considerable detail and aims to ensure consistency in approach (through descriptions of how many participants are required, what the occlusion cycle should comprise, how much training to give, how many task variations to set, data analysis procedures, and so on).

With occlusion, participants carry out tasks with an in-vehicle system (stationary within a vehicle or vehicle mock up) whilst wearing computer-controlled goggles with LCDs as lenses which can open and shut in a precise manner. Consequently, by stipulating a cycle of vision for a short period of time (1.5 s), followed by an occlusion interval (1.5 s), glancing behaviour is mimicked in a controlled fashion. Two key metrics are stipulated:

- Total Shutter Open Time (TSOT – the total time required to carry out tasks when vision is available)
- Resumability (R – the ratio of total shutter open time to task time when full vision is provided, considered to provide an indication of the ease by which a task can be resumed following a period without vision [16].

The occlusion approach was selected for this study as it offers a relatively simple method of assessing the visual demand of an in-vehicle user-interface based on performance data. A key advantage of occlusion is that criteria now exist defining acceptable/unacceptable limits for TSOT and R. The US-based Alliance of Automobile Manufacturers (AAM) states that tasks where TSOT is greater than 15 s are unacceptable [17] and should not be operated by a driver in a moving vehicle. This value was derived based on relationships between the number/duration of glances and the likelihood of lane deviations [18,19]. Moreover, the value considers the visual demand associated with an established "acceptable" in-vehicle secondary task, manually tuning a radio [17,19]. Alternatively, the Japan Automobile Manufacturers Association (JAMA) state "the operation of a display monitor is prohibited" for tasks with TSOT values greater than 7.5 s ([20], p. 7). This more conservative value was predominately based on research, later reported by Asoh and Iihoshi [21], which focused on drivers' feelings of anxiety whilst performing secondary tasks of varying visual demand. More recently, Stevens, Burnett and Horberry [22] defined a criterion value for TSOT (termed a Demand Reference Level-DRL) which accounted for the variability in data from occlusion studies. The DRL was based on a review of the literature, together with data from their own occlusion studies, expert reviews and a survey of drivers' attitudes. An equation stated that TSOT (mean + "spread") should be less than 8.0 s.

The latest research in this area has recently been summarised in a new set of guidelines published in February, 2012 that have emerged from the US [23]. This work follows a similar approach to the original AAM proposals, but includes more recent research relating to the visual demand of varying user-interfaces [24]. Importantly, the final recommendation is closer to the JAMA and Stevens et al. view, in that they consider that tasks are unacceptable if TSOT is greater than 9 s.