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Dynamic MouselabWEB: Individualized information display matrixes

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This paper introduces Dynamic MouselabWEB, a computerized process tracing tool that was designed to create flexible decision-making settings that are similar to real life. While Dynamic MouselabWEB is an extension of MouselabWEB, it differs in that it creates individualized information display matrixes (IDMs) rather than presenting predetermined IDMs, so participants decide on the attributes and alternatives before the decision task. This structure can improve the involvement of decision-makers in the decision process and it gives researchers a chance to observe decision-making behaviors and to explore new decision-making strategies when the decision task has only the decision-makers' important attributes and appealing alternatives. In order to measure the effect of this dynamic structure, two groups of students worked on job selection tasks, one in the Dynamic MouselabWEB program ($n = 32$) and one in the traditional MouselabWEB program ($n = 20$). Results indicate a significant difference between the decision-making behaviors of these two groups. The students who chose a job on Dynamic MouselabWEB were informed more and they spent more time on task than the other group; in other words, they were involved more in the decision process.

Keywords: decision-making, process tracing, information display matrix, MouselabWEB

This article consists of three main sections; the first section is dedicated to a literature review in order to make the readers familiar with the background information, the second is created for technical aspects of the software, and the last section explains the experiment.

Literature review

Decision models

There are mainly two approaches to studying decision-making behavior: 1) the outcome-based approach and 2) the process tracing approach (Harte & Koele, 2001). The outcome-based approach attempts to construct mathematical models for the relationship between input (information) and output (decisions) to reveal the cognitive patterns underlying decision-making processes. This approach has been applied for over two centuries (Abelson & Levi, 1985; Brehmer, 1994; Dawes, 1979; Einhorn, Kleinmuntz, & Kleinmuntz, 1979; Ford, Schmitt, Schechtmann, Hults, & Doherty, 1989; Westenberg & Koele, 1994), but it has a large number of limitations. For example, the approach implies fitting mathematical models to data on decisions (output) in various situations (input) in order to infer the underlying decision-making processes without taking process data into account. According to Svenson (1979), these models provide surface descriptions of the processes rather than a detailed information concerning stages in actual decision processes. As a result, researchers have suggested that cognitive processes cannot be sufficiently understood by solely studying input-output relationships and other research methods need to be included (Ford, et al., 1989; Payne, Braunstein, and Carroll, 1978; Svenson, 1979). Researchers can overcome these concerns by employing the process-tracing approach, which focuses on patterns of information acquisition rather than the output (i.e., the decisions). In most process-tracing studies, information is presented in an information display matrix which has at least two alternatives which are characterized by at least two attributes (Ford et al., 1989). By observing the information acquisition process, such as the amount of time spent making decisions, sequences of information acquisition and the amount of information accessed, researchers have gained insights into cognitive processes and developed more accurate predictive models (Einhorn & Hogarth, 1981).

Process tracing methods

Several methods have been used to monitor information acquisition processes, such as verbal protocols (Jarvenpaa, 1989), eye movement recording (Russo & Dosher, 1983), information display boards (Payne, 1976), and the Mouselab system (Payne, Bettman, & Johnson, 1988). In earlier process-tracing studies, such as those carried out toward the end of the 1970s, participants were asked to make a decision by looking at information on cards located in envelopes on an information display board (Payne, 1976). In order to access information about a particular attribute for a particular alternative, the participant had to open the associated envelope and read the card, which would then be placed back in the envelope. In the meantime,

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the researcher would write down the sequence of acquisitions and the number of times that the envelopes were opened. Computerized process tracing, such as the Mouselab system, employs computer graphics to display information displaying an information display matrix (Payne et al., 1988). With this system, the values of attributes are concealed in boxes on a screen instead of in envelopes. Each box is opened when the mouse cursor is moved over it (mouseover), and it remains open until the cursor is moved away (mouseout). Only one box can be opened at a time (Payne et al., 1988).

In addition to offering all the features of Mouselab, MouselabWEB makes it possible to carry out research on the Internet (Willemsen & Johnson 2004, 2011). MouselabWEB (www.mouselabweb.org), which uses Web technology (Javascript, HTML, PHP, and MySQL), has open-source codes, released under GNU General Public License v3.0, so researchers can add new features. Moreover, participants do not need to download plugins or other software; all they need is access to the Internet and a mouse to use a MouselabWEB page. Along with MouselabWEB there are other computerized process tracing tools, such as ISCube (Tabatabai, 1998), MouseTrace (Jasper & Shapiro, 2002), phased narrowing (Jasper & Levin, 2001; Levin & Jasper, 1995), active information search (Huber, Wider, & Huber, 1997; Williamson, Ranyard, & Cuthbert, 2000), P1198 (Andersson, 2001) and ComputerShop (Huneke, Cole, & Levin, 2004).

Decision strategies

According to Payne, Bettman, and Johnson (1992), a decision strategy is a "sequence of mental and effector (actions on the environment) operations that transform some initial state of knowledge into a final knowledge state so that the decision maker perceives that the particular decision problem is solved" (p. 109). Knowing about decision makers' cognitive processes enables us to infer the decision strategies used and it also enables us to predict future decisional behavior and decision outcomes (Payne, Braunstein, & Carroll, 1978). Furthermore, if we are better informed about people's decision strategies we can design better decision support systems (Browne, Pitts, & Wetherbe, 2007; Montgomery, Hosanagar, Krishnan, & Clay, 2004; Bettman et al., 1993). Although it is seldom possible to precisely identify a particular decision strategy, researchers can identify types of strategies by using process measures (Ford et al., 1989). In general, decision strategies can be classified as being either compensatory or non-compensatory. With compensatory strategies, decision makers make tradeoffs between different values of multiple attributes and they engage in extensive information processing (Stevenson et al., 1990). When a large amount of information is gathered in the process, this usually indicates that participants are employing compensatory decision-making strategies (Ford et al., 1989). The weighted adding strategy, for example, is a compensatory strategy that requires decision makers to multiply each attribute's subjective value by its importance weight to obtain an overall value for each alternative (Abelson & Levi, 1985). Non-compensatory strategies are selective in the sense that decision makers restrict their attention to only part of the available information (Beach & Mitchell, 1978) and eliminate alternatives that do not meet their requirements. One example of this is the lexicographic strategy (LEX), which selects the option with the best value for the most important attribute. According to the cost/benefit framework, the choice of a decision strategy is a function of both costs, i.e. the effort required to use a rule, and benefits, i.e. the ability of a strategy to select the best alternative (Beach & Mitchell, 1978; Russo & Dosher, 1983). By using this framework, the decision maker has a large repertoire of decision strategies, and he/she chooses one of these strategies contingent on the decision tasks' characteristics, such as complexity of the decision task and time pressure, to adapt to decision settings (Bettman et al., 1993). In addition to decision task-based variables, another important variable that affects the use of various decision-making strategies is the level of involvement of the decision maker. Involvement is considered to be an important mediating variable of consumer behavior (Mitchell, 1979). For example, an extensive information search might indicate a higher level of involvement (Mittal, 1989).

Process measures

When participants process information in a decision task, computerized process tracing tools record time-dependent mouse events, e.g., mouseover (opening of boxes), mouseout (closing of boxes), the order in which boxes are opened, the amount of time boxes remain open, selected options, and total elapsed time since the display first appears on the screen automatically. By using this event-based data, several measures can be computed to characterize decision-making behavior, which are generally divided into depth, content, and sequence of searches (Ford et al., 1989; Jacoby, Jaccard, Kuss, Troutman, & Mazursky, 1987; Jasper & Shapiro, 2002, p. 370). Depth measures focus on determining how extensively the participants attempted to acquire information. This includes decision-making time (Hogarth, 1975; Pollay, 1970), proportions of information sought (Payne, 1976), reacquisition rates (Jacoby, Chestnut, Weigl, & Fisher, 1976), number of acquisitions (Bettman et al., 1993), and the average amount of time spent per item of information acquired (Bettman et al., 1993). Content measures are used to quantify the relative weights assigned to the various types of information and they refer to exactly what information was acquired and which options were chosen. Content measures include the total amount of time spent on the information in the boxes (Bettman et al., 1993), time spent on the most important attribute/-s, and the proportion of time spent on the most important attribute. It is common to ask subjects to rate the importance they assign to attributes by using a Likert rating scale question after the decision task. When this is done, the attribute with the highest rating is considered to be the most important one. Sequence measures are used to describe whether information selection behavior was primarily attribute- or alternative-based. An alternative-based search indicates that decision makers first consider several attributes of the same alternative before proceeding to the next one. In contrast, when they compare alternatives across attributes first, this is referred to as an attribute-based approach. A common metric for defining search patterns is the Search Index (SI) (Payne, 1976), which measures the relative use of alternative-based versus attribute-based searches. The index ranges from -1 to +1, indicating a completely attribute-based or a completely alternative-based information search, respectively. If both types of search patterns are used equally, the index is 0. A positive index value is often assumed to indicate the usage of compensatory strategies (e.g., weighted adding strategies), whereas a negative index value is interpreted as being an indicator for more non-compensatory strategies (e.g., elimination-by-aspects strategies). Böckenholt and Hynan (1994) proposed the Strategy Measure (SM), another index for search patterns, as they found in a simulation study that the SI is unreliable when the number of alternatives and attributes is not identical. When the number of attributes is larger than the number of alternatives, a positive SI index is more likely and when the number of attributes is smaller than the number of alternatives, a negative SI index is more probable. The SM index also ranges from -1 to +1. Other variables for sequences of searches are variability in the amount of information searched per option (Payne, 1976), and variability in the amount of information searched per attribute (Klayman, 1982). Lower values for these two measures indicate that decision processing is more evenly spread across all the attributes or alternatives, respectively.

A new tool: Dynamic MouselabWEB

MouselabWEB

MouselabWEB focuses on the acquisition of information to make inferences on the nature of the underlying cognition and test existing decision models. To do that, it presents information on an attributes-alternatives matrix. In most computer-based displays, the attribute values are hidden behind boxes. Participants navigate through a task by moving the mouse and they can reveal information as much as they need to make a decision. Most computers record time and sequence of acquisitions with sufficient precision (1/60 th of a second), resulting in a record of box openings and closings. The interpretation of information-acquisition data is based on two testable assumptions (Costa-Gomes, Crawford & Broseta, 2001) about the relationship between search and cognition: The first, occurrence, states that if information is used by a decision-maker, it must have been seen by opening a box. The second, adjacency, assumes that information is acquired, rather than memorized because of limitations in short-term memory and the low cost of (re-)acquisition.

Motivation behind Dynamic MouselabWEB

Dynamic MouselabWEB was motivated by the following aims:

1. Overcome limitations of predetermined informational structures

One of the limitations of IDMs is that the researcher has to determine the options, attributes and information available (Jacoby et al., 1987). This can be alleviated by using an individualized structure., Aschemann-Witzel and Hamm (2011) suggests as one of the possibilities for further development of IDMs:

> Another method suggested by Jacoby et al. (1987, p. 155) is an individualized IDM; this takes account of the criticism of IDM based on overly stark predefined informational structures: Before the IDM-survey is carried out, each individual participant is asked which of the product attributes are important to him or her, so that only these criteria are then offered in the matrix. (p. 4)

2. Create stimulus close to real-life decision settings

In the age of the Internet, consumers tend to narrow down the options and criteria via online shopping websites so they can choose the best option. In light of this, researchers should prepare IDMs with this kind of dynamic structure. Allowing decision makers to create their own IDMs rather than working with predefined ones resembles certain real-life information environments more closely.

3. Encourage researchers to discover new decision strategies

As Huber (1980) states, future research should not be limited to decision strategies which are discussed in the literature:

> The list of simple strategies discovered so far covers only a subset of all possible simple strategies. ... At least some of the simple strategies are incomplete. For example, the lexicographic-ordering strategy assumes that the decision maker first selects the most important dimension. It is not clear what happens if there are two or more most important dimensions. (pp. 187–188)

4. Increase the involvement of participants in decision processes

In decision research, involvement is directly related to motivation to get information. We believe that if participants can decide what they want to know about the options that they are considering, they will be more motivated to get more information in the decision process.

5. Make it freely available for other researchers

Dynamic MouselabWEB is free software like MouselabWEB, so researchers can redistribute it and/or modify it under the terms of the GNU General Public License v3.0.

Technical aspects

Dynamic MouselabWEB is an extended version of MouselabWEB and uses all the features of MouselabWEB. In this section, we list the basic features of MouselabWEB and discuss the technical requirements for MouselabWEB, and then we explain the structure of Dynamic MouselabWEB.

Basic features

An experiment based on MouselabWEB generally has more than one HTML page, such as an introduction page, pages for warm-up tasks, a decision task page and a survey page. Each page is linked to the following page by defining "nextURL," which is placed in the source code. MouselabWEB pages can be generated using the MouselabWEB Designer (http://www.mouselabweb.org/designer/index.html), an online editor program. The main purpose of the Designer is to generate the MouselabWEB boxes structure, which can be designed by using different features. According to the study aim, researchers can use default features or create new features. Mainly, MouselabWEB has these basic features: 1) there are different options for box openings and box closings, 2) boxes can be fixed or counterbalanced or random, 3) you can include a header row/column for alternatives and attributes, 4) the layouts of boxes and selection buttons can be changed by altering CSS files, 5) the background scripting automatically saves the data, and the process data is sent to and stored on a database, 6) a questionnaire can be included before/after the decision task.

Dynamic features

MouselabWEB uses MySQL, which is a relational database management system. We created three more tables in addition to the table that stores the process data to make MouselabWEB dynamic. The functions of these three tables are as follows:

- $T_{alternatives}$ stores information about the alternatives,
- $T_{attributes}$ stores information about the attributes,
- T_{values} stores the values of the attributes.

The Electronic Supplementary Material (ESM) 1 explains the columns of these three tables and the information that they store. In order to use Dynamic MouselabWEB codes, you have to create these tables in a database. Our study tables can be created by running the SQL script in ESM 2.

In Dynamic MouselabWEB two additional screens are present before the decision task: 1) "Choose the alternatives screen", which uses information from the $\mathrm{T}_{\mathrm{alternatives}}$ table in the database (Figure 1 shows a capture of this screen; see ESM 3 for page source code. 2) "Choose the attributes screen", which uses information from the $\mathrm{T}_{\mathrm{attributes}}$ table in the database (Figure 2 shows a screen capture). This page's source code is in Electronic Supplementary Material 4.

Although we choose to display these two screens in that order, it is possible to change the order of the screens or omit one of them and use predefined attributes /alternatives instead.

After these two selections, the names of columns and rows, and information of boxes can be obtained from the database by using the tables' associations. To do this, we added steps in the source code of the decision task screen. The source code of the decision task is provided ESM 5. For a screen capture of a decision task, see Figure 3.

To create a dynamic decision task, researchers should determine the alternatives, the attributes, and the attributes' values in advance. Then they need to create three tables in the database to keep their information and should make necessary changes in the codes of the sets of alternatives/attributes. Figure 4 illustrates the process of creating a study in Dynamic MouselabWEB.

Figure 1. A screen capture of a set of alternatives screen.

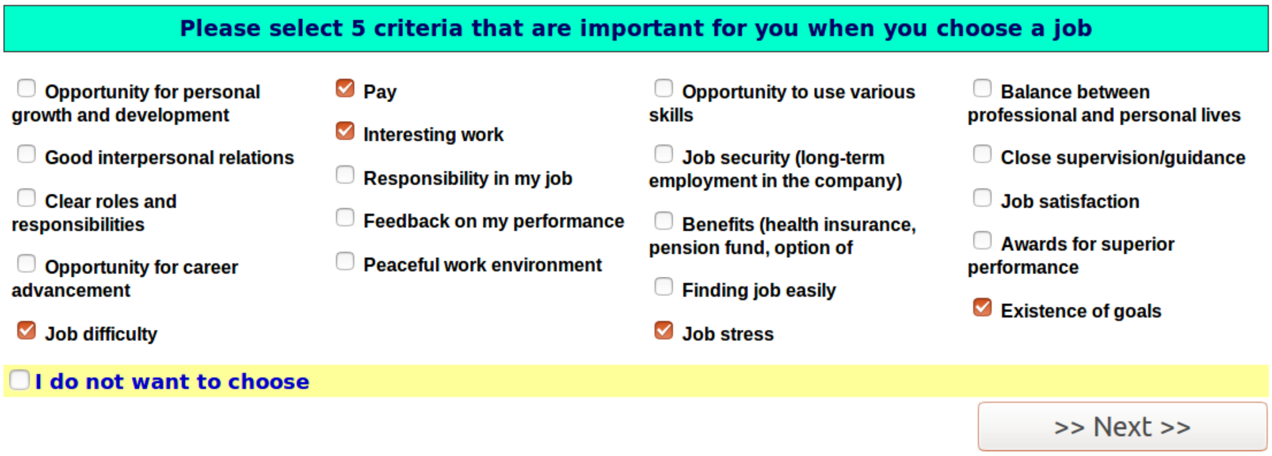

Figure 2. A screen capture of a set of attributes screen.

Technical requirements

Dynamic MouselabWEB has the same technical requirements as MouselabWEB. We recommend to visit the download page (http://www.mouselabweb.org/download.php), where you can find the program files and a guide that explains how to install the software and launch an experiment. We encourage you to create a MouselabWEB page using MouselabWEB Designer to get familiar with the software. You can design an experiment in an offline environment or with an online version of MouselabWEB. Basically, you need a web server and PHP/MySQL capabilities on your system as well as a database to store the study data. You can find all the necessary files that you have to put in the study folder in ESM 6.

Experiment

In order to illustrate the dynamic structure of Dynamic MouselabWEB, we conducted an experiment that compares the results of two decision tasks using the same amount of information presented either in Dynamic MouselabWEB or in MouselabWEB (the control).

We formulated three hypotheses based on the process measures:

H_1: The dynamic structure of a decision task has an effect on decision-making behavior.

H_2: Participants using a dynamic structure will access more information and spend a longer amount of time on a decision task, which indicates a difference in terms of involvement.

H_3: The Dynamic MouselabWEB group will place less attention on the most important attribute than the control group.

We mainly wanted to make a general statement about the effect of the dynamic structure as it is stated in H_1. Even though H_1 is related to H_2, we want to use different analysis techniques to test these two hypotheses. We used more than one dependent variable to represent decision-making behavior to test H_1. On the other hand, H_3 suggests that these two groups have different approaches for the most important attribute. Since the dynamic decision task has more than one important dimension, we assume that the group in this task give less attention to the most important attribute than the other group.

Method

Participants

The target group was Turkish undergraduates studying in their final year in statistics departments. 32 undergraduates (19 female, 9 male, 4 not answered, M_{age}

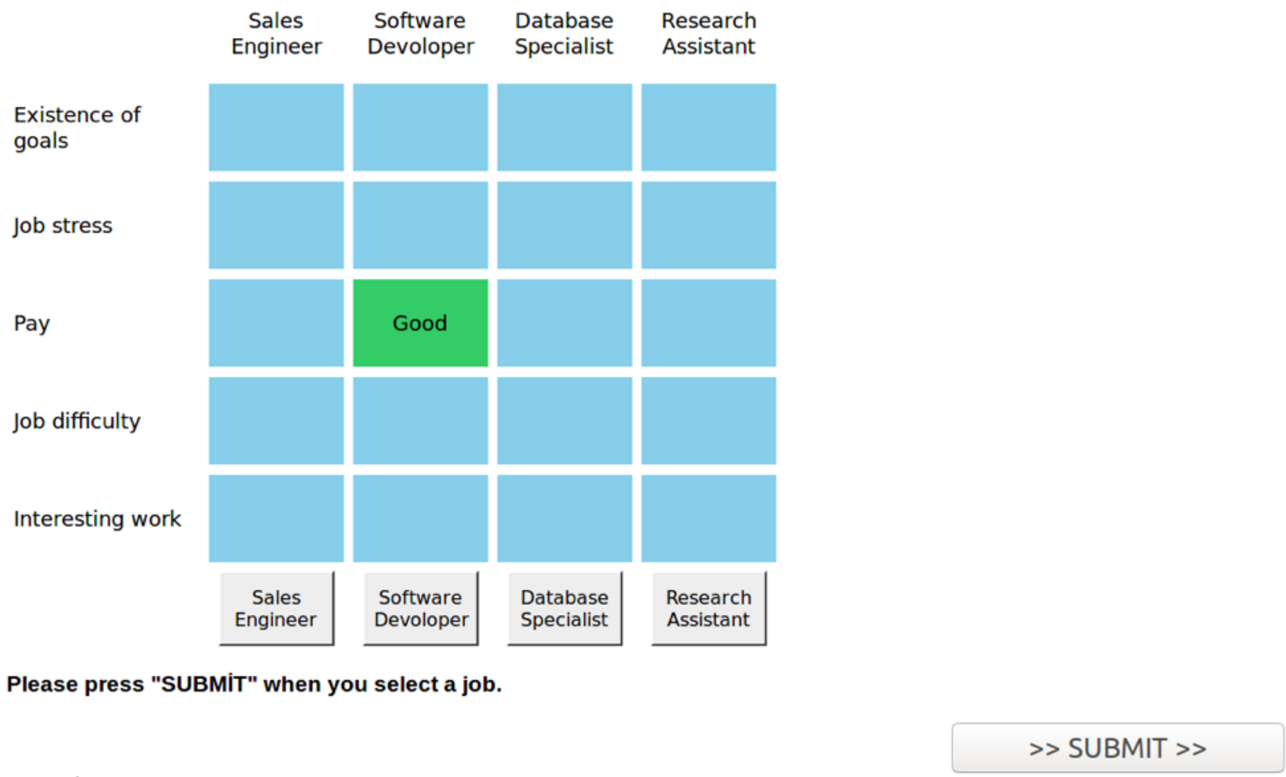

Figure 3. A screen capture of a decision task.

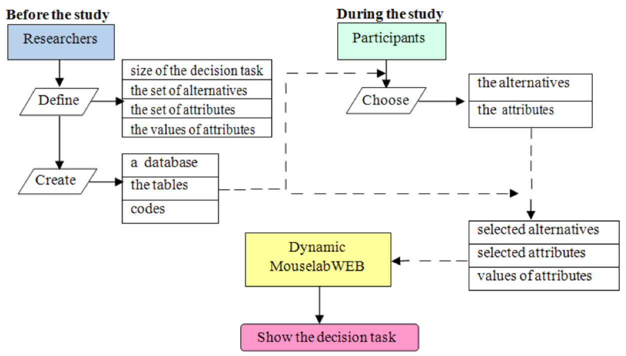

Figure 4. The flowchart of a study in Dynamic MouselabWEB. The dotted lines represent the background scripts that show screens and obtain information from the database, whereas the unbroken lines denote researchers/participants' activities.

= 22.9, SD = 0.71) from various universities selected a job on Dynamic MouselabWEB and 20 undergraduates (10 female, 10 male, M_{age}= 23.6, SD = 1.47) selected a job on MouselabWEB.

Programs

We designed two job selection tasks with four alternatives and five attributes. The stimuli in MouselabWEB have a traditional setup in which the alternatives and the attributes are selected by the researcher, whereas in the dynamic decision task, participants can choose the alternatives and attributes from the sets before the task.

Design

In the Dynamic MouselabWEB study, to define the set of alternatives, we determined sectors in which people who graduated in Statistics might work. These sectors are IT, banking, insurance, industry, market research, and education. Then we used job search websites to determine the particular occupations. In the preparation phase, we selected 21 jobs and prepared a study link that includes the decision task, and we sent this link to 10 undergraduates and asked for their feedback. Based on their responses, we omitted 11 jobs and added 2 new jobs to the set. The set of attributes has 20 attributes which were collected from various studies. To determine the attribute values, we turned to eight specialists who have worked for many years in their sectors. We asked them to rate 20 attributes on a 7-point scale (from worst to best) for each job and each sector (overall rate). After the specialists had assessed all the jobs, we consolidated these assessments into a single table which has 20 attributes and 12 jobs.

Procedure

In the Dynamic MouselabWEB task, participants were asked to choose four jobs from the set of alternatives and five attributes from the set of attributes. The option "I do not want to choose" was added to the sets, and if this option was selected, the predetermined alternatives/attributes were shown in the main decision task. In the MouselabWEB task, participants were asked to choose one job in the main decision task in which the alternatives and attributes were predefined. This decision task also had four jobs and five attributes. Both studies include introduction pages and two warm-up tasks before the stimuli. The survey links, which included the decision tasks, were sent to students between March and May 2018. They were

Table 1. Means and Standart Deviations of the Dependent Variables and t-test Results.

	Decision Task Group				t-test for Equality of Means		
	Dynamic MouselabWEB Group (n = 32))		MouselabWEB Group (n = 20)		*t*	*df*	*p*
Process measures	Mean	SD	Mean	SD			
Percent of unique boxes examined	0.84	0.18	0.70	0.26	2.33	50	.02
Number of acquisitions	42.16	19.25	26.60	15.66	3.04	50	<.01
Reacquisitions Number	25.41	17.14	12.70	11.66	3.18	50	<.01
Total time in decision (s)	42	24	31	16	2.10	50	.04
Time spent on the most important attribute (s)	8.32	5.90	8.86	7.20	-0.29	46	.78
Proportional time on the most important attribute	0.20	0.10	0.32	0.24	-2.19	24	.04
Strategy Measure	-0.41	3.93	-0.95	3.20	0.52	50	.61
VarAlt	0.03	0.03	0.05	0.06	-1.59	50	.12
VarAtt	0.02	0.02	0.03	0.05	-1.46	22	.16

Note. VarAlt: variance in the proportion of time spentprocessing each alternative, VarAtt: variance in the proportion of time spent processing each attribute. The significance level is .05.

informed about the project by an email and invited to the study. They did not receive any compensation in return.

Data preparation

The process data was used to create nine variables reflecting on decision-making behavior. To measure the total amount of processing, we used four depth measures: 1) total time spent on decision(s), 2) number of acquisitions, 3) number of reacquisitions, 4) percentage of unique boxes examined. To assess selectivity in processing, we used two content measures: 1) time spent on the most important attribute(s), 2) proportional time spent on the most important attributes. To define the pattern of searches, we use three sequence measures: 1) Strategy Measure, 2) variance in the proportion of time spent processing each alternative (VARalt), 3) variance in the proportion of time spent processing each attribute (VARatt).

Results

Since we expected the dependent variables to be correlated ($0.2 < r < 0.8$), we initially performed a Multivariate Analysis of Variance (MANOVA) with dependent variables that meet MANOVA's assumptions. These dependent variables are: Total time in decision-making, number of acquisitions, time spent on the most important attribute, and variance in proportion of time per alternative. The result of the MANOVA shows that the decision-making behavior of participants who selected their attributes and alternatives before the decision task is statistically different from the control group, $F_{(4,43)} = 3.18$, $p = 0.02$. As indicated in H_1, we can conclude that the dynamic structure of the decision task has an impact on decision-making behavior. An independent samples t-test was used to examine the effects in more detail. Table 1 presents the descriptive statistics (means and SDs) of the dependent variables and t-test results.

Table 1 shows that the two groups are significantly different in terms of all the depth measures: percent of unique boxes examined, number of acquisitions, reacquisitions number, total time in decision. As predicted in H_2, the dynamic group processed more information (i.e., higher number of acquisitions, higher number of reacquisitions, and higher percentage of unique cells examined) and spent longer time in decision process, so we conclude that this group was involved more in decision-making. Lastly, the two groups differed in terms of "proportion of time spent on the most important attribute" ($p = 0.04$). As stated in H_3, it can be concluded that when participants define the attributes and the alternatives of the decision task, they spend less time on the most important attribute. The data file is placed in Electronic Supplementary Material 7.

Discussion

The idea underlying Dynamic MouselabWEB emerged from the observation that there are no open-source tools available that can create individualized IDMs. In this paper, we have described Dynamic MouselabWEB, which was designed to create individualized IDMs that make it possible for participants to choose the attributes and the alternatives before the decision task. By using Dynamic MouselabWEB, researchers can avoid the problem of predetermined informational structures and generate more realistic decision settings. Additionally, we believe that if participants can decide what they want to know about the options that they will consider, they will be more motivated to get more information about the decision process. To define Dynamic MouselabWEB's position in decision studies, we can compare it with The method of Active Information Search (AIS). Huber, Wider, and Huber (1997) introduced the method of AIS, in which the subject gets a basic description of the task, and has to ask questions to receive additional information. These questions are recorded and answers are provided in printed form. In an AIS experiment, the researcher has to prepare possible questions in advance to present their answers during the experiment. Similar to this, in Dynamic MouselabWEB the researcher has to define all attributes and alternatives about the task to display them on the screens. Additionally, both methods put the participant in an active position. The main difference between these two approaches is that in an AIS experiment, the participants have to ask questions about what they need to know to solve the problem, but in Dynamic MouselabWEB the participants see all possible attributes and alternatives at once and choose among them to create the task. In order to test the program, a study was conducted to compare the decision-making behavior of two groups which selected a job from same-size decision tasks presented in Dynamic MouselabWEB versus MouselabWEB. The results of the study show that 1) the dynamic structure of a decision task has an effect on decision-making behavior; 2) the dynamic group processed more information and spent more time on decision processes; and 3) the dynamic group spent less time on the most important attribute. The job choice task is just one example of any number of decision-making contexts, and this new program can be used for many decision-making tasks with larger sample sizes. We encourage researchers to use Dynamic MouselabWEB to observe decision-making behavior because individualized IDMs include only those criteria that are important for decision makers and only those options that have the potential to be selected. Thus, Dynamic MouselabWEB creates a decision-making environment with more than one important dimension, an issue that Huber (1980) raised. Naturally, the outcomes of this should be explored by future research. Since it is an open-source program, other researchers can easily access the codes and adapt them to their research.

Electronic Supplementary Material

Supplementary material available online at https://doi.org/10.11588/jddm.2019.1.63149

- ESM1.DatabaseTables (doc).
- ESM2.CreateDMWTables(sql).
- ESM3.ChooseAlterScreen(php).
- ESM4.ChooseAttriScreen(php).
- ESM5.DecisionScreen(php).
- ESM6.MouselabWEB_Files(zip).
- ESM7.Data(sav).

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