Tracing the Impact of Item-by-Item Information Accessing on Uncertainty Reduction

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The impact of item-by-item information accessing on uncertainty reduction is studied under self-selected and researcher-constrained information accessing. Study 1 showed that, at both the aggregate and the individual level, subjective uncertainty reduction assumes several distinct patterns, with the dominant pattern conforming to an accelerating or linear power function. Study 2 revealed that different subjective-uncertainty-reduction patterns tend to be associated with within-options versus within-properties searches. Implications of the findings and the procedure are discussed.

Since the 1960s, researchers have expressed concern about the limitations of traditional "static" methods for studying decision making. This led to the development of three process-oriented methodologies. The earliest, the verbal-protocol approach taken from Newell and Simon (1972), is exemplified in the consumer literature by the work of Bettman (1971) and Wright (1973). Also discussed by Newell and Simon (1972), eye movement and fixation analysis was introduced in the consumer literature by Russo (Russo 1978; Russo and Rosen 1975). The third approach, behavioral-process analysis, was independently proposed by Jacoby (1975, pp. 210–213; see also Bettman and Jacoby 1976; Chestnut 1975; Kohn-Berning and Jacoby 1974; Jacoby, Szybillo, and Busato-Schach 1977; Jacoby et al. 1976) and Payne (1976). Since then, the behavioral-process approach has undergone considerable evolution.[1]

This article extends the behavioral-process approach to study the impact of item-by-item information accessing on a higher-order cognitive process—namely, on uncertainty reduction. After discussing the relationship of information acquisition to higher-order mental processes in general and to uncertainty reduction in particular, the procedure is outlined. Study 1 examines uncertainty reduction under conditions in which information is self-selected by the subject. Study 2 then examines uncertainty reduction under conditions in which information acquisition is constrained by the experimenter. Both studies provide data on reactivity.

INFORMATION ACQUISITION AND HIGHER-ORDER MENTAL PROCESSES

Decision making is generally conceptualized as a series of stages operating in sequential and recursive fash-

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[1]For a more complete discussion, see Chestnut and Jacoby (1977, 1982), Ford et al. (1989), Jacoby (1977), and Jacoby et al. (1976, 1987). For a detailed definition of "behavioral process," see Jacoby (1977).

ion. This perspective is found across a variety of disciplines, which include consumer behavior. Although different formulations employ varying terminology and numbers of stages, all assume that the individual is first exposed to and acquires information from the external environment, interprets and evaluates this information, integrates it with other information, and uses some or all of this data as the basis for judgments and subsequent choice behavior. An assumption of such formulations is that events occurring at earlier stages exert an impact on subsequent stages (see, e.g., McGuire 1972). If a particular item of information is *not* acquired, then, unless the same meaning is also conveyed by another item of information that *is* acquired, it is logical that the former item cannot influence subsequent decision making. Alternatively, once acquired, information may have no effect or may have a number of different effects, depending on how it is processed. Thus, the amount, content, and sequence of information input are expected to impact on the formation, development, and change of such higher-order processes as beliefs, attitudes, evaluations, images, impressions, and intentions.

Each decision-making stage is assumed to operate as a dynamic process in its own right. Consider information acquisition. When much information exists, the individual necessarily attends to some information items before others, and the sequence in which information is acquired may have considerable impact on higher-order mental processes and the decision outcome (see Jacoby et al. 1987). Verbal-protocol-, eye-fixation-, and behavioral-process-tracing procedures were all developed to capture such information-accessing sequences.

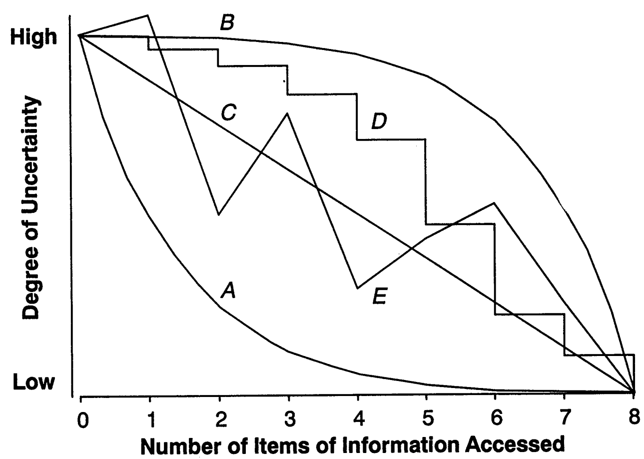
It is unfortunate that, while also conceptualized as dynamic processes, the other decision-making stages have generally been studied via static methodologies that involve comparing simple pre- versus postdecision measures. This precludes study of how the piecemeal input of information affects the molecular evolution of these processes and limits the possibility of finding that these phenomena develop in nonlinear shifts of potential theoretical and/or practical significance. To better study higher-order process phenomena (such as changes in perceived uncertainty), one needs a methodology that is commensurate with, and that permits more adequate testing of, our process conceptualizations. Specifically, effective process methods need to capture the incremental development of higher-order cognitive processes in a way that links them directly, in a one-to-one fashion, to item-by-item information acquisition. This article describes such a procedure and uses it to examine the assumption that information acquisition leads to uncertainty reduction.

THE RELATIONSHIP OF INFORMATION ACQUISITION TO UNCERTAINTY REDUCTION

According to Bauer (1960), consumer behavior reflects an individual's reaction to the perceived risks as-

FIGURE 1

POTENTIAL UNCERTAINTY-REDUCTION CURVES



sociated with purchase. Bauer theorized that perceived risk is a function of the "consequences" (particularly the negative consequences) that might ensue from a behavior and of the "uncertainty" of these consequences. The 1970s saw articles that theorized about and studied the strategies consumers use for reducing uncertainty (and, thereby, perceived risk); the concept of uncertainty continues to be of interest to consumer researchers (see, e.g., Currim and Sarin 1989; Folkes 1988; Kahn and Meyer 1991; Kahn and Sarin 1988). As a concept, uncertainty plays a key role in many theories of human judgment, learning, and decision making (see Bettman, Johnson, and Payne 1991, p. 51; Hammond, McClelland, and Mumpower 1980, pp. 65–71), with many theories considering how information acquisition affects uncertainty. Our focus here is on subjectively perceived uncertainty, not on objectively determined uncertainty, as it is the former that is generally the focus of theorizing in consumer behavior.

Plotted as a function of information acquisition, various subjective-uncertainty-reduction curves seem plausible. Consider the question "Why would a decision maker ever look at less diagnostic information when more diagnostic information is available?" A decelerating power function would occur if consumers sought the most diagnostic information first, with each information item being less informative than the one that preceded it. This should produce rapid uncertainty reduction early in the process followed by decreasing amounts of uncertainty reduction with additional information (see the asymptotic convex curve designated curve *A* in Fig. 1). Some evidence for this is provided by Jaccard, Brinberg, and Ackerman (1986, Table 1).

The above strategy presumes the decision maker has some idea of an information item's diagnostic value prior to acquiring that information. However, this may not be the case. While individuals know the type of information prior to accessing, they may have no idea whether the particular information item (e.g., 72¢) will be something they view positively, negatively, or neutrally. Hence, an opposite, concave subjective-uncertainty-reduction curve might occur under various scenarios (see curve *B* in Fig. 1). Individuals may suspend judgment because they feel they do not have enough information on which to base a change in their uncertainty. For such individuals, subjective uncertainty would be expected to remain at or near the initial level of uncertainty for a period of time. This would also occur if individuals experienced a need to avoid closure (see Kruglanski 1989, pp. 17–19) by withholding a decision until late in the process. This amounts to a strategy of "do not commit yourself because you never know what additional information you may encounter." Further, individuals may be reluctant to report their true level of uncertainty in order to not appear publicly committed to a decision any earlier than necessary.

A third subjective-uncertainty-reduction curve would be essentially linear, occurring when acquisition of each successive item of information reduces uncertainty by the same amount (see curve *C* in Fig. 1). Alternatively, a fourth curve (curve *D* in Fig. 1) would occur if subjective uncertainty were reduced in stepwise fashion. Suppose individuals required several items of information before their feelings of uncertainty changed from their initial levels, then acquired several additional items before updating their judgments of uncertainty, and so forth. Depending on the size of these steps, subjective uncertainty reduction would be best fit by a linear, an accelerating, or a decelerating function. The taking of equidistant "steps" (e.g., acquiring three items of information before modifying one's rating of subjective uncertainty, taking another three items of information before remodifying one's rating, and so on) would best be represented by a linear function. The taking of large steps at first (e.g., acquiring 10 items of information) followed by the taking of successively smaller steps (e.g., nine items, then eight items, and so on) before changes in uncertainty ratings would be reflected by an accelerating curve. The taking of small steps at the outset, followed by the taking of successively larger steps would be reflected by a decelerating curve.

Fifth, consider situations in which obtaining a particular item of information causes individuals to become less certain of what they thought they knew. Such increases in perceived uncertainty might be infrequent and of small magnitude, or frequent and of large magnitude, as individuals progressed through the decision process. Although such people might eventually reach the same low level of uncertainty, molecular tracing of this process might reveal substantial spikes reflecting uncertainty increases at one or more points (see curve *E* in Fig. 1) that would be masked by standard pre- versus postdecision assessments.

Thus, although uncertainty may begin and end at the same point, a number of uncertainty-reduction curves seem possible. All curves in Figure 1 reflect substantial uncertainty reduction, yet all arrive at the end point differently. To identify the functional form of uncertainty reduction we must trace these curves as they develop. Using a variation of standard behavioral-process procedures, we examined how respondents' ratings of subjective uncertainty were affected by each separate item of information accessed (i.e., we mapped the impact of item-by-item information acquisition on uncertainty reduction). Item-by-item assessment permitted an exploration of which, if any, of the plausible curves best characterize subjective uncertainty reduction. Do different curves occur? This possibility has been discussed conceptually but has not been empirically demonstrated.

EXTENDING THE BEHAVIORAL-PROCESS PARADIGM: HIGHER-ORDER COGNITIVE TRACING

The behavioral-process approach is a simulation strategy that involves the following. A problem solver first is provided with either a choice or an evaluation problem and then is given access to an external information environment that may be used in solving the problem. The information may be authentic, hypothetical, or some combination of the two and may be conceptualized as a two-dimensional "options × properties" plane or as a three-dimensional "options × properties × sources" cube. *Options* represent objects (e.g., brands of breakfast cereal), organizational entities, people, and alternative courses of action, and so on. *Properties* represent describable characteristics of the options (e.g., brands of breakfast cereal differ in terms of their price, brand name, ingredients). *Sources* represent entities from which properties × options information can be obtained. Third, problem solvers are permitted to acquire as much or as little of the available information they desire, in any order, and as often as they wish, while a trace of this information-accessing behavior is captured and preserved. In addition to learning the outcome of the process (e.g., what option was selected or how various options were ordered), the data indicate "how much" and "just which" information went into arriving at that outcome and in what order the information was accessed. Such data have been referred to as the depth, content, and sequence of information accessing, respectively. It is the latter that is of particular concern here.

Conceptually, the extension is simple. It involves introducing an additional "side step" into the information-accessing process such that, immediately after accessing one item of information but before accessing another, the individual is required to respond to a scale that taps into a higher-order mental process (e.g., attitudes, intentions, degree of certainty). Only after this side step is completed can the subject access more information, if desired. With the assumption that the side step is not reactive (in the sense of affecting either subsequent information accessing or the dependent variable itself), this permits examination of the molecular changes in the higher-order process as a function of item-by-item information acquisition. Hence, the procedure is termed *higher-order cognitive tracing* (HOCT).

STUDY 1: THE SHAPE OF UNCERTAINTY REDUCTION

Study 1 provides data on both the methodological concern of reactivity and the competing hypotheses regarding the shape of subjective uncertainty reduction. Conducted in 1981 through 1983 as part of a series of National Science Foundation–sponsored investigations on the consumer use of health and safety information, this study was detailed in the final unpublished report submitted to the National Science Foundation (see Jacoby and Jaccard 1984); the HOCT procedure was later described in Jacoby et al. (1985, p. 111). All studies in this series of investigations examined consumer risk perception and choice behavior in regard to three widely used, technologically complex products having health and safety implications. The products (birth control methods, household insecticides, and automobile tires) were selected after an extensive literature review coupled with on-site discussions with policymakers at the Consumer Product Safety Commission, the Food and Drug Administration, the National Bureau of Standards, and the National Highway Traffic Safety Administration. These products were identified by the policymakers as having high levels of health and safety risks.

Subjects

Solicited via newspaper advertisements, there were 138 subjects, all above the age of 18. Most (58.5 percent) were female, and 96 percent of these women were of childbearing age (18–40 years old). Although most respondents (63 percent) were unmarried, nearly all reported being sexually active, which made the birth control decision a meaningful one. Nearly all either owned or drove automobiles, which made the tire decision meaningful.

Design

The investigation is conceptualized as a 3 × 2 factorial containing three product levels (birth control, insecticides, and tires) and two tracing levels (tracing and no tracing). To avoid potentially biasing measurement effects, each subject was randomly assigned to participate in only two of the six cells, one of which had a tracing condition and one of which had a no-tracing condition. Because of occasional computer malfunctions, data are available only for 133 subjects in the tracing condition and 129 subjects in the no-tracing condition.

Procedure

Subjects were instructed to "select the safest" option from a set of available purchase options. The options × properties (O × P) matrices varied in size and were 10 × 12 for birth control methods, 10 × 17 for insecticides, and 11 × 13 for tires. Options were identified abstractly as "option 1," "option 2," and so on. The properties for each product are identified in the Appendix. All information was stored in a Cromemco Z-2H microcomputer, which enabled the randomization of the presentation order for both option and property information across respondents. Respondents commenced reaching their "safest product" decision by communicating with the computer via a light pen attached to a color video monitor. After an initial series of person-machine interactions to review the task instructions and rules, an empty cell O × P matrix was displayed on the monitor and the respondent was asked to indicate which information s/he wanted to see for which option. Subjects were permitted to access a single item of information at a time by touching the screen with the light pen, whereupon the desired information appeared on-screen almost instantaneously.

After acquiring the first item of information, subjects could choose to make a safest product decision at that point or to acquire additional information. If they chose the latter, the matrix was displayed again, and subjects indicated which item of information they next wished to consider. Subjects continued until they felt ready to make a safest product decision, which was also indicated with a light pen. A more complete description of the procedure is found in Jacoby et al. (1984, 1985). Immediately after accessing each item of information, subjects in the HOCT condition used a light pen to respond to the following on-screen 100-point (anchored by "extremely uncertain" and "extremely certain") graphic rating scale: "How certain are you at this point that you will be able to select the safest (birth control method) from among the (10 types) available?" To provide a frame of reference, beginning with the second trial, the response immediately preceding this question was displayed in a contrasting color. The no-tracing condition consisted of the standard behavioral-processing task (i.e., no uncertainty rating was taken after each item of information was acquired). This condition enabled us to determine if the tracing procedure (i.e., asking a question after each item of information was accessed) exerted a reactive effect.

Assessing Reactivity

The procedure could be reactive in three respects. Does providing a rating after each item of information is acquired affect the person's (1) subsequent information accessing, (2) ratings of uncertainty reduction, or (3) evaluations of the information accessed or other related phenomena? Study 1 addressed the first of these

TABLE 1

COMPARING THE IMPACTS OF TRACING AND NOT TRACING ON THE DEPTH OF SEARCH

	Birth control methods				Tires				Insecticides			
	$\bar{X}$	SD	SE	t	$\bar{X}$	SD	SE	t	$\bar{X}$	SD	SE	t
Total number of items accessed:												
No tracing	29.60	16.84	2.43	−.05	22.42	15.48	2.42	.05	20.10	13.17	2.08	−.32
Tracing	29.80	18.04	2.69		22.40	12.90	1.88		21.00	12.41	1.94	
Total number of different items accessed:												
No tracing	26.80	18.04	2.69	−.03	22.15	14.31	2.24	.04	18.65	12.20	1.93	−.38
Tracing	26.89	15.79	2.35		21.02	12.00	1.75		19.63	11.38	1.78	
Percentage of full matrix accessed:												
No tracing	16.97	9.05	1.31	.05	14.62	10.36	1.62	.06	10.88	7.04	1.11	−.44
Tracing	16.88	10.12	1.51		14.50	8.67	1.27		11.55	6.70	1.05	
Number of different options considered:												
No tracing	9.23	2.96	.43	1.04	6.56	3.03	.47	.18	6.78	3.13	.50	−.15
Tracing	8.51	3.64	.54		6.45	2.98	.44		6.88	3.12	.49	
Number of different properties considered:												
No tracing	7.71	3.30	.48	−.19	6.68	3.44	.54	.07	6.05	3.71	.59	−1.20
Tracing	7.84	3.49	.52		6.64	2.72	.40		7.00	3.43	.54	

NOTE.—There were 45 individuals who were subject to tracing conditions in the birth control decision, 47 in the tires decision, and 41 in the insecticide decision. There were 48 individuals who were subject to no-tracing conditions in the birth control decision, 41 in the tires decision, and 40 in the insecticide decision.

issues; study 2 addressed the second. The concluding Discussion section addresses the third.

The fundamental depth and sequence of search statistics (see Jacoby et al. [1976, p. 309; 1987, pp. 151–152] for a description of these statistics) were compared for the tracing and no-tracing conditions (see Table 1). For the five key (and partially correlated) depth statistics, none of the differences in the 15 cases approached meaningful levels of significance. Table 2 compares the tracing and no-tracing conditions for the sequence of search. When the four basic transition indices were used, only one of twelve t-tests revealed a significant difference between the tracing and no-tracing conditions (type 3 sequence for tires; $p < .04$).

Thus, across the combined 27 tests (15 for depth and 12 for sequence), there was only one finding of statistical significance. This suggests that the HOCT procedure does not affect either the depth or the sequence of information accessing, at least when only a single sidestep rating is taken.

The Impact of Information Acquisition on Subjective Uncertainty

Pre- versus Postdecision Uncertainty Reduction. Examining uncertainty reduction typically involves comparing pre- versus postdecision task uncertainty scores. In this study, this approach revealed that subjective uncertainty generally did not start at 100 percent or decrease to 0 percent. Subjects seemed willing to live with decisions that brought uncertainty down to an acceptable, albeit nonzero, level. Taken both before any information was accessed and after all information accessing had been completed, the mean initial and mean terminal subjective uncertainty ratings on the 100-point scale were, respectively, 76.18 and 18.36 for birth control procedures, 82.38 and 32.09 for tires, and 82.17 and 40.32 for insecticides. In each case, there was a large and statistically significant ($p < .01$) pre- to postdecision decrease in subjective uncertainty. Proportionally, the drop was greater for birth control methods than for the other products, although it was still appreciable (i.e., over 50 percent) in the other two cases. (Note that the amount of information accessed was not related to the final uncertainty score: $r = .01$ for birth control, .03 for tires, and −.05 for insecticide.) Although the anticipated reduction in subjective uncertainty materialized, two questions remain: How does subjective uncertainty reduction develop? Is its shape linear, accelerating, or decelerating?

Tracing Item-by-Item Subjective Uncertainty Reduction: Aggregate-Level Analysis. For each subject in the HOCT condition, a plot of the item-by-item uncertainty rating was constructed with the amount of the search on the abscissa and the level of uncertainty on the ordinate. Because different individuals engaged in searches of different lengths, the amount of information accessed was operationalized in terms of the "percentage of accessing completed," which ranged from zero to 100 percent. Each individual's search length was divided into n equal portions, where n represented the total number of items accessed by that person. Thus, if person A had accessed 50 items of information, his percentage of accessing completed could be partitioned into 50 units, each of which would represent 2 percent of the total search, and the uncertainty rating that was provided after having accessed 10 items would have been plotted at the twentieth percentile.

TABLE 2

COMPARING THE IMPACT OF TRACING AND NO TRACING ON THE SEQUENCE OF SEARCH TRANSITIONS

Type	No tracing	Tracing	t
Birth control methods:			
1	.021	.024	.35
2	.381	.371	.18
3	.373	.406	.61
4	.225	.199	.99
Tires:			
1	.010	.021	1.84
2	.250	.329	1.24
3	.553	.434	2.10
4	.187	.216	1.17
Insecticides:			
1	.028	.023	.54
2	.260	.287	.44
3	.539	.477	1.07
4	.173	.213	1.41

NOTE.—Transition type 1 is "same options, same properties"; type 2, "same options, different properties"; type 3, "different options, same properties"; type 4, different options, different properties."

TABLE 3

MEANS AND SE OF THE UNCERTAINTY RATINGS

	Birth control		Tires		Insecticide	
Period	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
1	74.82	5.84	81.21	4.34	81.98	4.44
2	69.15	6.22	81.99	3.81	87.34	3.08
3	68.10	5.67	82.79	3.29	84.82	3.36
4	64.33	6.25	78.89	3.48	84.12	3.57
5	65.90	5.93	80.06	3.87	81.17	3.29
6	64.65	5.85	76.30	3.83	81.11	3.35
7	60.55	6.23	73.98	4.12	80.01	3.94
8	63.86	5.59	72.05	4.07	81.29	3.21
9	62.42	5.59	75.58	3.95	76.04	3.91
10	62.64	5.49	70.47	3.67	77.71	3.33
11	59.95	5.83	67.86	4.29	75.52	4.04
12	57.42	5.59	69.38	4.38	76.27	3.58
13	56.61	5.34	67.55	4.58	67.97	3.77
14	53.07	5.53	62.85	4.43	68.69	4.08
15	50.38	4.48	65.62	4.39	65.52	4.05
16	48.47	4.98	62.23	4.95	64.24	4.56
17	45.01	4.72	61.05	4.87	57.43	4.36
18	41.46	4.43	59.70	4.61	54.43	4.70
19	36.91	4.65	55.08	5.04	54.95	5.06
20	22.11	3.45	40.36	4.91	41.84	5.07

The curves within each cell were aggregated as follows: The axis for the percentage of accessing completed was divided into 20 five-point intervals. Next, all subjective uncertainty ratings falling within a given interval were averaged and then plotted at the midpoint of that interval. For subjects who accessed fewer than 20 items of information, this meant no rating in some intervals; for subjects who accessed 21 or more items, this meant two (or more) ratings were combined in some intervals. Table 3 lists $\bar{X}$'s and SEs. These procedures enabled subjective uncertainty reduction to be examined at both an aggregate and an individual level.

On the basis of the aggregated data for all HOCT subjects, it appears that, for each of the products, uncertainty reduction follows a nonlinear or concave pattern best approximated by a decelerating power function (see Fig. 2). To test whether uncertainty reduction follows a nonlinear or a concave pattern, the following exponential model was specified:

$$y_i = \frac{\beta_1 - \beta_0 \exp(-\beta_2) + (\beta_0 - \beta_1) \exp(-\beta_2 x_i)}{1 - \exp(-\beta_2)} + e_i,$$

where $e_i = N(0, \sigma^2)$; y_i represents subjective uncertainty; x_i represents the percentage of accessing completed; β_0 represents initial uncertainty; and β_1 represents the final-level or "residual" uncertainty. The model is similar to one employed to infer risk attitude from judgments made under uncertainty (Currim and Sarin 1989). The parameter β_2 determines the shape of the uncertainty curve. The model is defined for all values of β_2 other than zero. Values of β_2 close to zero denote a linear reduction of uncertainty. Positive values of β_2 that are statistically different from zero imply a decelerating power function for uncertainty reduction. In contrast, negative values of β_2 that are statistically different from zero imply an accelerating power function. We chose this functional form because the parameter β_2 was found to be sensitive to small differences in curvature and to departures from linearity.

The parameters were estimated by means of a nonlinear least squares algorithm. The Marquardt compromise was utilized to iteratively converge at the parameter estimates (see Draper and Smith 1981, p. 471). The parameter estimates of the model for each of three product categories are shown in Table 4. The approximate t-statistics are shown in parentheses. For each product category, the parameter estimates of β_2 are negative and are statistically different from zero ($p < .0001$), which indicates an accelerating power function. The parameter estimates for β_0 are all significantly smaller than one, which indicates that the initial level of uncertainty as inferred from the fitted model is less than 100 percent, the maximum possible. Further, all parameter estimates for β_1 are significantly greater than zero ($p < .001$), which indicates that the final level of uncertainty as inferred from the fitted model is higher than the minimum possible (i.e., zero percent).

Regression diagnostics and probability plots indicate that the assumption of normal errors is not violated. In each case, the test runs on the Studentized residuals and the autocorrelation function both indicate the lack of significant autocorrelation. The quality of fit for the three data sets is evident from the plots of the fitted values overlaid with the observed responses. This is illustrated in Figure 3 with the birth control data.

FIGURE 2

UNCERTAINTY REDUCTION FOR THREE PRODUCT CATEGORIES: BIRTH CONTROL, TIRES, AND INSECTICIDES

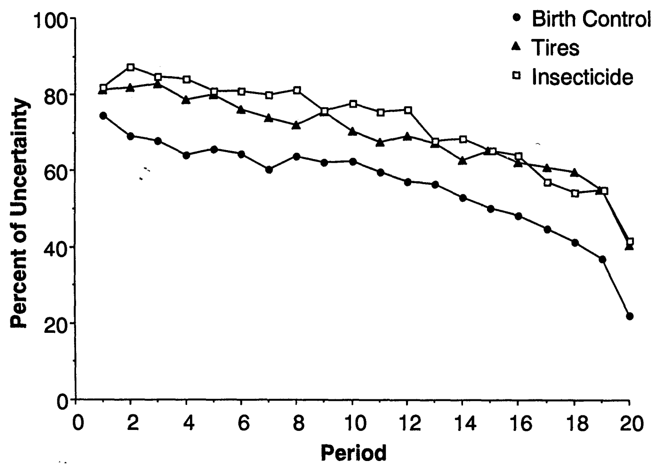


TABLE 4

PARAMETER ESTIMATES FOR THE EXPONENTIAL MODEL

	β_0	β_1	β_2
Birth control	.687	.269	−3.225
	(24.48)[a]	(13.22)	(6.75)
Insecticide	.852	.446	−2.722
	(12.96)[a]	(26.93)	(7.04)
Tires	.816	.479	−2.037
	(10.59)[a]	(21.75)	(3.40)

NOTE.—*t*-statistics are in parentheses.

[a]Hypothesis 0 (the null hypothesis) is $\beta_0 = 1.00$; hypothesis A (the alternate hypothesis) is $\beta_0 \neq 1.00$.

There may be advantages to keeping subjective uncertainty high. As long as consumers remain uncertain about which option is safest or best, they may be encouraged to seek more information and, as a consequence, may select a safer option than they would otherwise. Examining this possibility involves comparing the amount of information selected by those exhibiting a concave uncertainty-reduction curve with those exhibiting a convex uncertainty-reduction curve. Because too few subjects exhibited a convex curve, we could not conduct such a comparison. However, note that the final aggregate uncertainty scores for birth control methods (18.36), tires (32.09), and insecticides (40.32) are inversely correlated to virtually all the statistics reported in Table 1, especially to the mean number of items acquired (29.8, 22.4, and 21.0, respectively). On the basis of the individual-level data, the correlation between the final uncertainty level and the number of acquired items is .035 for tires, .012 for birth control methods, and −.046 for insecticides, which indicates that acquiring a larger number of items does not necessarily lead to lower final uncertainty. A potential explanation is that people whose uncertainty is less easily resolved continue to search for more information.

Tracing Item-by-Item Uncertainty Reduction: Individual-Level Analysis. Research to date has presented and discussed only aggregate data. The HOCT approach also enables examination of the disaggregated data to determine if they generally support or disconfirm the aggregate findings.

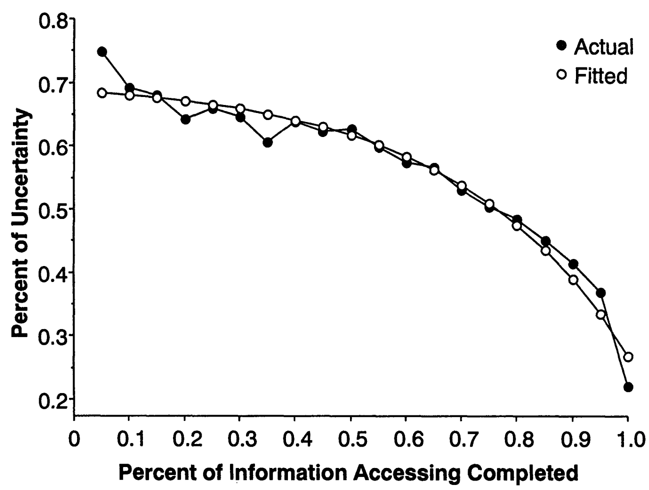
Visual inspection revealed that the curves of some individuals assumed dramatically different shapes. In accordance with this, an exponential model was fit separately for each individual. This procedure smooths out fluctuations in subjective uncertainty, permits study of the heterogeneity in parameter estimates across subjects, and is important in avoiding the potential of parameter estimates at the aggregate level that is subject to aggregation fallacy (Jaccard and Dittus 1990; Jaccard and Wood 1986). For example, if the parameter estimate at the aggregate level indicated that uncertainty reduction was an accelerating function concave to the origin, this would occur if uncertainty were a sharply accelerating function concave to the origin for more than half the subjects and a slightly decelerating function convex to the origin for the remaining subjects.

To study the heterogeneity in parameter estimates across individuals, we fitted the exponential model described earlier to the uncertainty ratings for each individual. The parameter estimates for β_2 were negative and were significantly different from zero for 32 percent, 47 percent, and 38 percent of the subjects in the birth control, insecticide, and tire groups, respectively. A negative value of β_2 indicated an accelerating power function concave to the origin. Parameter estimates for β_2 were close to zero for 56 percent, 50 percent, and 59 percent of the subjects in the birth control, insecticide, and tire groups, respectively, which indicated a linearly decreasing function. Parameter estimates for β_2 were positive and significantly different from zero (which indicated a decelerating function) for relatively few subjects—for 12 percent, 3 percent, and 3 percent in the birth control, insecticide, and tire groups, respectively. So, while some heterogeneity in β_2 parameter estimates across respondents surfaces in each case, the estimates for more than 90 percent of the subjects indicated an accelerating or linear reduction in uncertainty. This finding was generally supported when we employed a quadratic model in place of the exponential model.[2]

[2]Following one reviewer's suggestion, we estimated a quadratic model for each product category as having accelerating, linear, or decelerating uncertainty-reduction curves. Earlier, we had done this for the exponential model. Hence, we were able to study correspondence or robustness of such classification on the basis of both models. We found the correspondence to be good, particularly considering that the exponential model has approximate confidence intervals. Specifically, the correspondence was exact for 65 percent of the sub-

FIGURE 3

PREDICTED VERSUS ACTUAL UNCERTAINTY REDUCTION: BIRTH CONTROL



Discussion of Study 1

Based on three independent groups of respondents tested on three completely different consumer products, aggregate analyses yielded three remarkably similar curves, which suggested that the shape of subjective uncertainty reduction may be that of an accelerating power function. Although visual inspection suggested that the aggregate curves masked some differences, individual-level analyses revealed less heterogeneity than appeared to be the case. When one fits a model that smooths for error, 90 percent of the individual curves are best fit either by an accelerating function or by linearity. Thus, subjective uncertainty reduction is generally not a decelerating function. Notwithstanding this conclusion, the differences across subjects may be as meaningful as the aggregate uniformity across products and warrant additional exploration.

Although our principal objective was to map the impact of information on uncertainty reduction (not to explain why particular findings were obtained), the findings appear reasonable. First, the decision to select the safest option was relatively complex. Subjects had to evaluate not one, but a number of different options, each of which was described in terms of a number of articulated properties. Deciding on the safest option under these circumstances would typically involve evaluating several or all options along one or more properties and ruling out options along the way. Given 10 options, it seems that considerable uncertainty would remain after eliminating one, two, or three options and would dissipate most rapidly when only a few options remained. This would result in an accelerating curve for uncertainty reduction.

Second, different subjective-uncertainty-reduction patterns were observed at the individual level. These patterns may reflect stable, individual styles that people develop as a function of experience. Alternatively, they may reflect the effects of the particular information content accessed by the subject. It was unfortunate that, to avoid potential within-subject contamination, each subject was tested on only one of the three products by means of the HOCT. Although strong evidence has been found both here and abroad for the stability of information-acquisition patterns within individuals across different types of decisions (see Jacoby et al. 1978, Tables 5 and 8; Jacoby et al. 1981; Raffee et al. 1979), research needs to explore the possibility of stable uncertainty-reduction styles as well. Research should also be directed to examine the policy and applied implications of how information accessing influences the degree of uncertainty at the time of choice and usage.

The style in which subjects reduce uncertainty may be a function of several factors. Examples include individuals' levels of knowledge and experience in making comparable decisions, individuals' levels of involvement in the product category, the characteristics of the context (e.g., the number of alternatives, the number of relevant properties, the degree of variance in property values, and the correlation between property values), and the measurement scale and instructions used. Another factor that may affect uncertainty reduction is the information-acquisition *strategies* used by individuals. Some search patterns may be conducive to faster reduction, all else being equal. This is illustrated in study 2. Research could also provide insight into such aspects by fitting an uncertainty-reduction model to the data elicited from each subject to estimate subject-specific values of the uncertainty-reduction parameter (β_2) and then, in a subsequent step, attempting to explain the variation in this uncertainty-reduction parameter (with these estimates as dependent variable values) across subjects by employing the constructs described above as independent variables.

A third interesting finding concerns the content of information accessed. Despite their having access to the same information environment, subjects who exhibited similar patterns of uncertainty reduction typically did not acquire the same option × property information, and the few who did, did not do so in the same sequence. This suggests that it is not the specific information, per se, but how it is interpreted that affects uncertainty reduction.

Finally, it is interesting to note that ratings of subjective uncertainty generally did not begin at 100 per-

jects in the birth control context, 78 percent of the subjects in the tire context, and 77 percent of the subjects in the insecticide context. For the few subjects for which there was not perfect correspondence in classification, the magnitude of the difference in the estimated shape of uncertainty reduction from the two models was small. On the basis of the results described above, we conclude that there is good correspondence in the classification results from the exponential and quadratic models across subjects in the three different product categories.

cent or decrease to zero percent. Subjects rarely considered as much as half the available information, and they seemed willing to reach a decision after uncertainty was brought down to an acceptable level. The decision not to acquire additional information may reflect an avoidance of information overload.

STUDY 2: UNCERTAINTY AND SEARCH STRATEGIES

While informative, study 1 leaves a number of questions to be addressed. Two of particular interest are the following: (1) Although it appears not to affect the quantity or sequence of subsequent information accessing, does HOCT reactively affect the dependent variable of interest? (2) While study 1 found that, at both the aggregate and individual levels, subjective uncertainty reduction assumes either an accelerating or linear form, are there circumstances under which it would assume a different form? Study 2 was undertaken to extend the findings of study 1 in these regards.

Past research using behavioral-process approaches has specified at least two general classes of information-search strategies individuals may use (see Bettman and Jacoby 1976; Jacoby et al. 1976). One search strategy is primarily within properties and across options: when confronted with the information environment, the individual identifies the informational property (presumably) most important to him or her and then selects information about various options for that property. This is then repeated for the second most important property, for the third most important property, and so on, until a decision is reached. The second strategy is dominated by within-options and across-properties searches. The individual arbitrarily selects one option and scans all the information on properties deemed important. Then a second option is chosen, and information is again searched across properties for that option. The process is continued for each option (or for a subset of options) until a decision is made. The two different search strategies have been found to characterize a large number of individuals and have important implications for the quality of decisions ultimately reached (see Jacoby et al. 1987). The present study was undertaken to determine if specific forms of uncertainty reduction are associated with these search strategies.

Subjects

Subjects were 150 male undergraduates enrolled in introductory psychology at a northeastern university.

Design

Subjects completed an information-acquisition task in which they were presented information about seven new male birth control pills, labeled "pill A" through "pill G," which were being developed for use in the United States. At an initial testing session, subjects ranked the relative importance of 10 different information properties they might consider when evaluating a male birth control pill. The five highest ranked properties for a given subject were then used as the available information environment for that subject. However, rather than permitting the individual to access information in any order, information exposure was controlled by the experimenter. For half the subjects, information was provided on a within-properties, across-options basis. That is, the individual received information sequentially on the most important property about pill A, then pill B, and so on through pill G. Then, information was presented on the second most important property about pills A through G, and so on, until either all properties were presented or the subject indicated he was ready to identify the best male pill. The other subjects received information on a within-options, across-properties basis. That is, the individual was sequentially given all the information about pill A, beginning with its status on the most important property through the least important property, and then this process was repeated for pill B, pill C, and so on, until pill G or until the subject indicated he was ready to make a choice.

After each item of information was presented, half the subjects in each condition indicated how certain they were that they could choose the best male pill using a 21-point scale ranging from 0 to 100 in five-point increments and with the verbal anchors of "not at all certain," "slightly certain," "quite certain," and "extremely certain" under the numbers 0, 35, 70, and 100, respectively (see Jaccard et al. 1994). One-fourth of the subjects completed the same certainty scale but only after every third piece of information was presented. The remaining fourth of the subjects completed the task with no tracing and only after indicating that they had acquired all the information they wanted.

Assessing Reactivity

Potential reactivity (in terms of impact on the dependent variable of interest) was examined by comparing the mean final uncertainty ratings in the group that responded after each item of information versus the group that responded after every third item of information versus the no-tracing group. A one-way ANOVA indicated no statistically significant difference across the means ($F(2,147) = 1.03$, NS). In addition, mean uncertainty scores for the every-item group versus the every-third-item group were compared at selected points in the information-acquisition process common to both groups (e.g., mean uncertainty scores after acquiring the third piece of information, the sixth piece of information, and so on). In no case was the difference in mean uncertainty scores statistically significant.

Search Strategy and Uncertainty Reduction

Uncertainty-reduction curves were plotted for those who completed certainty ratings after accessing each item of information. The curves were categorized into common groups across individuals according to the category schemes suggested by study 1. Two independent judges made the classifications and had a 97 percent agreement rate. For the group given information on a within-options, across-properties basis, the dominant pattern (revealed by 42 percent of the subjects) was one in which uncertainty started out high and remained high until there was a sudden and dramatic decrease toward the end of information acquisition. This corresponds to the accelerating pattern of uncertainty reduction found in study 1. However, a distinctly different uncertainty reduction pattern dominated the across-options, within-properties group. For 58 percent of these subjects, stepwise reductions in uncertainty occurred after blocks of information were acquired.

The proportion of individuals revealing an uncertainty-reduction pattern of constant high uncertainty followed by a large reduction toward the end of information acquisition was compared in the two groups (.42 in the within-options, across-properties group versus .09 in the across-options, within-properties group), and the difference was statistically significant ($p < .05$). This was also true for a contrast comparison of two groups on the basis of the proportion of individuals exhibiting stepwise reductions in uncertainty after blocks of information were acquired (.58 in the across-options, within-properties group versus .08 in the within-options, across-properties group).

By means of the same procedures described for study 1, the uncertainty-reduction model described earlier was fitted to the data on a single-subject basis. Regression diagnostics and the autocorrelation function again tended to suggest normally distributed errors and a lack of meaningful autocorrelation. As with study 1, the results indicated a preponderance of either an accelerated reduction of uncertainty (as reflected by a negative β_2) or a linear reduction of uncertainty (as reflected by a near-zero value β_2) for both groups of individuals (approximately 85 percent of the subjects in each group). Again, there were a small percentage of individuals who exhibited decelerating functions, but they were the exception rather than the rule.

Discussion of Study 2

Although tentative, the results of study 2 suggest that different search strategies may be associated with different forms of uncertainty reduction. For within-options, across-properties searches, the most dominant uncertainty-reduction pattern was one in which uncertainty remained high until almost all options had been described. Because early in the process information had been acquired for only a few of the options available, it was difficult to judge what was the best option. It was not until some information was available for all options that we began to see reductions in uncertainty. This corresponded to an accelerating function. By contrast, for across-options, within-properties searches, some information about each option was obtained relatively early in the acquisition process for the properties most important to the individual. Thus, substantial reductions in uncertainty were likely as one moved through the information-acquisition process.

GENERAL DISCUSSION

Principal Findings

Although limited in generalizability, our studies suggest that, under most circumstances, subjective uncertainty reduction is most likely to assume an accelerating or perhaps a linear shape, especially for people employing a within-options, across-properties information-accessing strategy. Although various reasons appear plausible, we suspect that this tendency reflects the "need to avoid closure" discussed at length by Kruglanski (1989).

Our studies also illustrate the potential that HOCT has for studying the impact of item-by-item information acquisition on mental processes theorized to be affected by information acquisition, regardless of whether information acquisition is self-selected or investigator controlled. Many cognitive phenomena are postulated to operate as dynamic processes, with theorists sometimes postulating that, with information input, the phenomenon in question assumes a certain shape. For example, Fishbein and Ajzen (1975, p. 223–224) speculated that each successive item of positive information contributes less to total attitude. They state, "Generally speaking . . . the theoretical relationship between number of positive beliefs and attitude is described by" a curve assuming a concave accelerating shape. To date, such hypotheses remain untested, because the measurement methodologies typically employed in researching higher-order mental phenomena do not permit their study as dynamic processes. In contrast, HOCT is in greater correspondence with, and is, therefore, more suitable for testing, such process theories regarding the evolution and change of higher-order mental phenomena.

Related Procedures

Since study 1 was initially proposed, conducted, and the procedure briefly described (Jacoby et al. 1985, p. 111), similar procedures have surfaced elsewhere. Particularly, noteworthy is a procedure described by Hughes (1992). While watching or listening to a broadcast communication, subjects manipulate a dial (graduated from 1 to 100) to register their reactions to the communication on a dependent variable of interest. Although this procedure possesses advantages and has been used commercially, it has several drawbacks.

First, although appropriate for broadcast communications, it is uncertain how it can be used to study the impact of information obtained from static stimuli (e.g., print advertising, packaging, or other textual material). Second, it requires subjects to react to researcher-imposed information, yet it is *subject* control over information input that occurs during most consumer decision making. Third, given the cognitive demands of processing complex dynamic stimuli, it is questionable whether people have sufficient ability to render uncertainty judgments covering a set of options while simultaneously maintaining attention to investigator-controlled dynamic input. Fourth, because information input is controlled by the investigator, it precludes the possibility of assessing reactivity (i.e., whether making a simultaneous rating affects either the amount or sequence of subsequent information acquisition). Fifth, every communication can be conceptualized as consisting of a universe of information (Jacoby and Hoyer 1987, pp. 22–24). For example, a TV commercial may simultaneously convey verbal and/or numeric information via either the audio and/or video channel. This may occur in the presence of one or more individuals appearing on-screen who may or may not be acting independently. Each such individual necessarily possesses a variety of characteristics (e.g., gender, clothing) that are part of the communication. In addition, there may be music, a voice-over, or more than one image on the screen at a time. Given such complexity, Hughes' procedure generated ratings that represented global impressions, not reactions to discrete pieces of identifiable information acquired by the subject and known to the researcher. In contrast, the HOCT procedure was able to parse out the incremental impact of specific, identified items of information on the dependent variable of interest.

A procedure more similar to ours was described by Dahlstrand and Montgomery (1989). Requested information was provided on-screen along with a graphic rating scale having end points labeled "bad" and "good" that subjects used to rate each item before acquiring another. Evaluations were thus provided for only one option per trial. The data-aggregation and analysis problems this created were handled by the division of each subject's decision process into thirds, then by the use of a single good-bad value to represent each third (see Dahlstrand and Montgomery 1989, p. 155). However, this masked the incremental effect of item-by-item information acquisition on the dependent variable. Although the resultant data were not reported, their study incorporated a second procedure. After every tenth item was acquired, subjects rated, by means of a scale with "small chance–large chance" end points, how likely they were to select each of the five options. Aside from masking the incremental impact of information acquisition, this procedure can be used only for tasks and subjects evidencing long search lengths. Although apparently not yet used for this purpose, the mouse lab procedure (Payne, Bettman, and Johnson 1988) is also capable of being adapted to gather data such as ours.

Along with HOCT, these procedures all capture the impact of informational inputs on the evolution of and changes in higher-order mental processes. As these procedures become more generally known, not only will they make it possible to test a variety of theoretical propositions, but their very availability may also stimulate theory development.

Future Tasks

Further methodological research is required. First, although HOCT appears not to affect the amount and sequence of information accessing or the dependent variable of interest, reactivity may be manifested in other ways (e.g., on the evaluation of information). However, while tests for such forms of reactivity should be conducted, the more important forms of potential reactivity were addressed here. Had the procedure affected either subsequent information accessing or the dependent variable of interest, it would be fatally flawed and there would be no need to probe for other forms of reactivity.

Second, how many side steps can be used at one time? Here, a single side step was used to study uncertainty reduction. What if one wanted to also examine changes in affect as the task progressed, so that a second side step would be introduced? At what point would the procedure begin to affect either information accessing or the dependent variables of interest? Third, we employed a 100-point scale. A subsequent investigation of attitude formation used a nine-point scale. Given that respondents generally shifted their attitudes by only one or two points per information-accessing trial, the resultant variance was insufficient for fitting curves. Is there a minimum number of scale points that should be used? Fourth, as employed here, HOCT was used to study an overarching construct that applied to the entire task (namely, "How certain are you at this point that you will be able to select the safest option from among the *n* that are available?"). This may explain why uncertainty remained high for so long in study 1; subjects may not begin reducing uncertainty until they are able to reject some choice options. However, subjects generally move back and forth across options during most behavioral-process simulations, which allows them to acquire information regarding one option, then another. Accordingly, how does one plot continuous curves for individual options? As a concrete example, suppose the person was confronted with choosing among six different automobiles. Given that information accessing is likely to move erratically across the six options, how would one assess attitude formation for each automobile?

Notwithstanding the methodological challenges that remain, as demonstrated by the present investigations, intermediate cognitive tracing opens up for detailed study a wide variety of cognitive phenomena theorized to operate as processes but heretofore studied by means of static procedures.

APPENDIX

Properties for the Three Products

Properties are rank ordered in terms of the proportion of respondents selecting information on this property at least once.

Birth Control	Insecticides	Tires
How effective is it?	What is its killing effectiveness?	What is the price?
Are there health risks or side effects?	Does it kill these insects?	What is the tire quality grade?
Is it used by males or females?	Is it safe to use near children?	What is the mileage rating?
How difficult is it to use?	What is the hazard level?	What type of tire is it?
Does it interfere with the pleasure of sex?	Is it safe to use near pets?	Is there a warranty?
Does it affect later abililty to conceive?	Are there recommended safety procedures?	Is the tire puncture resistant?
How often does it require attention?	What is the form of administration?	What is the traction rating?
Does it require a doctor's attention?	What is the price?	Is the tire self-sealing?
Does it interrupt the sex act?	Is it a poison?	What is the temperature rating?
Are there psychological side effects?	What are the directions for its use?	What is the place of purchase?
What is the cost?	What is the first aid instruction?	What type of fiber is the tire made of?
Are there moral considerations?	Are there disposal instructions?	What is the tire's maximum load?
Does it prevent veneral disease?	Is it safe near flames?	What is the number of plies?
	Is there a safety cap?	What is the sidewall color?
	Does it have a directional spray cap?	
	What are the storage instructions?	

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