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Skill and Automaticity: Relations, Implications, and Future Directions

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ABSTRACT Automaticity and skill are closely related but are not identical. Automatic processes are components of skill, but skill is more than the sum of the automatic components. Automaticity and skill are similar in that both are learned through practice; this has implications for (1) current studies of the co-occurrence of properties of automaticity, (2) the relation between multiple resources and automaticity, and (3) the relation between control and automaticity. Many of the issues in automaticity may be resolved or at least revised by considering the role that automatic processes play in performing a skill.

RÉSUMÉ L'automatisme et l'habileté sont reliés mais non identiques. Les processus automatiques sont les composantes d'une habilité, mais celle-ci est plus que la somme de ses composantes automatiques. L'automatisme et l'habileté sont similaires en ce sens qu'ils sont tous deux appris par la pratique. Ceci a des implications sur (1) les études actuelles sur la co-occurrence des propriétés de l'automatisme, (2) la relation entre les ressources multiples et l'automatisme et (3) la relation entre le contrôle et l'automatisme. Plusieurs des questions portant sur l'automatisme pourraient trouver leur réponse ou du moins être reformulées par l'examen du rôle que jouent les processus automatiques dans l'exercice d'une habileté.

Psychologists have believed there is a strong relation between automaticity and skill since the last century. Bryan and Harter (1899) argued that automaticity was a necessary component of skill, that higher-level aspects of skill could not be acquired until lower level aspects had become automatized. LaBerge and Samuels (1974) echoed Bryan and Harter's position, arguing that there was not enough attentional capacity to consider higher-level aspects of skill until lower-level aspects had become automatized, thereby freeing attentional capacity for the higher-level aspects. Other researchers may not accept the idea that attentional capacity limits the acquisition of skill (e.g., Spelke, Hirst, & Neisser, 1976) or that automatization should be defined as a reduction in capacity demands (e.g., Kolers, 1975), but most would agree that automatization is an important aspect of skill.

The close relation between automaticity and skill raises several questions: Are automaticity and skill the same thing? Is there anything to skill besides automaticity? What does a skills perspective imply for studies of automaticity? The purpose of this article is to suggest possible answers to these questions.

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AUTOMATICITY AND SKILL

Skill is a term that is usually applied to performance of a complex task. The task itself is considered a skill, and those who perform better on it are considered more skilled than those who perform worse. More precisely, a task may be defined as a set of goals which a person tries to obtain, and a set of constraints to which the person must adapt in order to obtain the goals. Some of the constraints are part of the task environment, such as the rules of chess that define legal moves or the rules of baseball that define the strike zone. Other constraints are part of the performer, such as limits on working memory, limits on task-relevant knowledge, or even limits on strength and agility. Generally, we say that a performer who can obtain the goals is more skilled than one who cannot, and, of those who can obtain the goals, performers who adapt better to the constraints on the task are more skilled than performers who do not adapt as well.

This definition suggests that skill is relative rather than absolute. We may talk about skilled performers versus unskilled performers, but we immediately recognize that this is only a convenient fiction. There is no sharp demarcation between the skilled and the unskilled. Usually, skills are open ended; there is no maximum level of skill that can be attained (e.g., Wayne Gretzky may be the most skilled hockey player at present, but few would bet that his excellent record will never be surpassed). Indeed, none of the current theories of skill acquisition assume there are severe limits on the highest degree of skill than can be obtained (e.g., Anderson, 1982; Crossman, 1959; MacKay, 1982; Newell & Rosenbloom, 1981). Thus, the assessment of skill is a relative judgement: We may consider one individual to be more skilled than another, but we recognize that it may always be possible to find someone who is more skilled or less skilled than either of them.

Automaticity, in contrast with skill, refers to rather specific properties of performance. Tasks that can be performed quickly, effortlessly, and relatively autonomously are thought to be automatic and tasks that cannot be are thought not to be automatic (Hasher & Zacks, 1979; Jonides, 1981; Logan, 1978, 1979; Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Most treatments of automaticity deal with components of tasks rather than tasks as wholes (e.g., LaBerge & Samuels, 1974; Logan, 1978; Schneider, Dumais, & Shiffrin, 1984; Shiffrin & Dumais, 1981). Thus, automatic processes are thought to work in rather limited task environments compared to skills. Automatic processes may be viewed as specialists working on rather small aspects of the behavioural problem that the overall skill addresses. Skilled performance works on broader domains by recruiting large numbers of automatic specialists. For example, skilled copy typing depends on automatic reading (i.e., translating visual input into graphemes and words), automatic translation of words into motor commands for keystrokes, and relatively automatic timing and execution of keystrokes (Rumelhart & Norman, 1982; Shaffer, 1976).

The preceding discussion suggests that skills consist of collections of automatic processes that are recruited to perform the skilled task. There is widespread belief in this proposition among students of skill. However, few would argue that skilled performance is simply more automatic than unskilled performance. A skill is more than the sum of its automatic parts. If unskilled performance were simply less automatic than skilled performance, unskilled performers would be able to do whatever skilled performers could do, only less automatically. Clearly, this is wrong. Skilled performers are usually capable of much more than are unskilled performers, and often do more when faced with the same task (e.g., Britton & Tesser, 1982). For example, a novice guitarist may be able to work through the chording of a song slowly and painfully, while a skilled guitarist does so quickly and effortlessly, embellishing the song with transitional chords and bits of melody, varying dynamics and rhythm.

Skilled performers are usually more knowledgeable than unskilled performers. Some of the knowledge is in the form of automatic procedures and processes, but some is in other forms. Skilled performers usually know more about their capabilities and their strategic options than do unskilled performers, and this *metacognitive* knowledge allows them to make better use of their automatic procedures. Skilled performers usually have a lot of *declarative* knowledge about their skill that may not be relevant to performance of the skill. For example, skilled musicians usually know several brand names of instruments, where and how they are manufactured, and where to get the best deals in buying them. They also know who the contemporary musicians are, the kind of music they play, and their level of skill. They may also know something about the history of the music they play.

In summary, automaticity is different from skill in that it refers to more specific properties of performance, but it is closely related to skill in that it is an important component of skill. Skills consist of automatic procedures as well as metacognitive knowledge about how and when to use the procedures and declarative knowledge about the trappings and demographics of the skill.

AUTOMATICITY, SKILL, AND LEARNING

A very important similarity between automaticity and skill is that both can be acquired through practice. This fact accounts for their status as relative concepts: Automaticity and skill are acquired gradually over long periods of time; performance at intermediate stages of practice may be more skilled and more automatic than performance at early stages of practice, but it is probably less skilled and less automatic than performance at very late stages of practice. Indeed, there may be no limits on the degree of automaticity a process can attain, just as there appear to be no limits on the degree of skill a person can attain. There may be limits on our ability to measure automaticity and skill (i.e., we cannot measure further increases in automaticity with the dual-task criterion after the automatized task no longer suffers dual-task interference), but that does not mean that no further change is going on (cf. LaBerge & Samuels, 1974). There may be temporary asymptotes or plateaus in performance, which are surpassed as practice progresses (Bryan & Harter, 1899).

There is no doubt that high levels of skill are acquired only through extensive practice. A skilled performer cannot reveal secrets that would allow an unskilled performer to attain a high degree of skill overnight. It is debatable, however, whether automaticity can be acquired without extensive practice. Laboratory studies typically find that many sessions of practice are required to produce automaticity (Fisk & Schneider, 1983; LaBerge, 1973; Logan, 1979; Mowbray & Rhodes, 1959; Shiffrin & Schneider, 1977). However, some investigators have provided subjects with secrets that allow them to mimic automatic performance immediately: Ellis and Chase (1971) and Jones and Anderson (1982) provided subjects with alternate means of performing accurately on a memory search task[1] and found that search time no longer increased as strongly with the size of the set to be searched, mimicking automatic search. In these cases, it seems likely that subjects simply bypassed memory search rather than performing memory search more automatically. Indeed, it is possible that the alternate means of performing the task were more difficult or required more effort (and hence, were less automatic); the authors did not test other criteria for automaticity.

There are cases of perceptual automaticity that may not be produced by learning. A number of authors have suggested that easy perceptual discriminations, such as detecting a tilted line in a background of upright lines or detecting a red target in an array of black distractors, can be performed automatically. Indeed, the time to make such discriminations is often independent of the number of distractors, which is characteristic of automaticity; the discrepant targets seem to pop out of the display. Often, it is assumed that the automaticity of these perceptual discriminations is innate (i.e., not learned). We could also challenge the idea that the discriminations are innate; indeed, there is no evidence that they were not learned early in life, retaining their automaticity because they are practiced every day. We could also challenge the idea that they are automatic in the same sense that well-practiced memory search is automatic. Practice in memory search usually reduces dual-task interference (e.g., Fisk & Schneider, 1983; Logan, 1978, Exp. 1), but cuing the target by making it discrepant from the distractors may not reduce dual-task interference (e.g., Logan, 1978, Exp. 3). Moreover, well-practiced memory search transfers well to other sets of targets and distractors (e.g., Kristofferson, 1977; Schneider & Fisk, 1984), whereas searching for a red target in a background of black distractors probably would not transfer well to search for a red target among reddish-orange distractors or for a blackish-blue target among black distractors.

Studies of easy perceptual discriminations seem to tap the tuning of the perceptual system, distinguishing the discriminations it finds easy to make from the discriminations it finds difficult. There is no evidence that different mechanisms are used for easy and difficult discriminations (i.e., difficult discriminations may be slower because they tax the perceptual system more than

[1] Ellis and Chase (1971) coloured nontargets red or made them smaller than the targets so a simple colour or size discrimination could distinguish targets from nontargets without any comparison of the probe item with the memory set. Jones and Anderson (1982) drew their targets from one category and their nontargets from another so that identifying the category to which the probe belonged was sufficient to discriminate targets from nontargets without any comparison of the probe item with the memory set.

easy discriminations do). By contrast, automatic performance is often thought to rely on different mechanisms than nonautomatic performance (e.g., Schneider et al., 1984).

Recently, Hasher and Zacks (1979) have claimed that some automatic processes, such as noting event frequencies, may not be learned. As evidence for their proposition, they show that the ability to note event frequencies does not change much with increasing age or with pathological states that supposedly reduce the amount of attentional capacity. Again, it is possible that people acquire the ability to note event frequencies early in life, so it need not be innate, and they practice it daily, so it need not change with age or pathology (see also Fisk & Schneider, 1984).

Alternatively, Hasher and Zacks (1979) may be confusing two separate meanings of the term automatic. In the context of this paper and most of the literature, the term is usually used to attribute properties, such as speed, effortlessness, autonomy, etc., to a specific process. In natural language, the term can also refer to inevitable consequences of conditions and actions, as when rain automatically wets the sidewalks or when a raise or promotion automatically changes one's tax status. For frequency judgements to be automatic in the first sense, there must be a specific process that explicitly encodes frequency information; that is, there must be a specific process to which the attribution of automaticity can be addressed. It is possible, however, that frequency is not encoded explicitly by any specific process. Consider, for example, Hintzman's (1976) position that separate representations of each encounter with a stimulus are encoded and retained, and that frequency judgements are based on counting or estimating the number of encoded representations at the time of retrieval. From Hintzman's position, frequency information is encoded automatically in the second sense of the term; that is, frequency information is encoded as an inevitable consequence of encoding separate representations of each encounter with a stimulus, but there is no process that explicitly encodes frequency at the time the stimulus is encoded that could be described as automatic in the first (i.e., conventional) sense of the term.

In summary, there is clear evidence that practice is important in producing automaticity, which suggests that automaticity may be learned; but, it remains possible that some forms of automaticity may not be learned, so we cannot conclude with any degree of certainty that learning is necessary to produce automaticity. However, there are other interpretations for the studies that suggest that some forms of automaticity may not be learned, so those studies do not allow us to conclude that learning is not necessary to produce automaticity. Thus, it may be best to conclude simply that learning is important in producing automaticity, just as it is important in producing skill. Indeed, the similarities between skill and automaticity should reinforce our faith in this conclusion.

A SKILLS PERSPECTIVE ON ISSUES IN AUTOMATICITY

The idea that automaticity is learned and that attributions of automaticity are relative judgements suggest that automaticity should be viewed as a continuum, like skill, with no discrete end points. This view contrasts markedly with the common view of automaticity as a dichotomy (i.e., between *automat-is* and *automat-isn't*), which leads theorists to define automaticity in terms of binary-opposite properties (e.g., Hasher & Zacks, 1979; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). The continuous or relative view of automaticity has important implications for some controversial current issues in the recent literature. Some investigators have tried to determine whether the various properties of automaticity co-occur, without considering the possibility that the various properties develop with practice. Others have discussed the relation between automaticity and the current concept of multiple resources, and still others have discussed the relation between automaticity and control. Each of these issues can be informed and, to some extent, laid to rest by considering the similarities between automaticity and skill. That is the purpose of the remainder of this article.

Relative Automaticity and Co-Occurrence of Properties

Recently, several investigators have addressed the internal consistency of the concept of automaticity by assessing the co-occurrence of various properties of automaticity (e.g., Kahneman & Chajzyck, 1983; Paap & Ogden, 1981; Regan, 1981). The logic of these studies has been to determine whether a process that is automatic by one criterion (i.e., load effects or dual-task interference) is also automatic by another criterion (i.e., autonomous or obligatory processing).[2] If it is, then the concept of automaticity is internally consistent; if it isn't, then the concept is not internally consistent, and perhaps should be rejected. Thus, Regan assessed the co-occurrence of effort and autonomy, showing that newly-acquired Armenian letters produced a load effect in an identification task and, at the same level of practice, produced Stroop-like interference characteristic of autonomous processes. Paap and Ogden assessed the co-occurrence of effort and autonomy in another way, showing that letter encoding, which appears to be obligatory in most tests, nevertheless produced dual-task interference. Kahneman and Chajzyck addressed a similar issue, showing that Stroop interference could be reduced (i.e., diluted) by adding another word to the display, as if the interfering word and the new word competed for capacity. These results suggest that effortful processes can be autonomous and that autonomous processes can be effortful, which may be interpreted as evidence against the internal consistency of the concept of automaticity. If this evidence is taken seriously, perhaps the concept should be abandoned or rejected.

However, the hypotheses actually tested in the experiments did not necessarily support the conclusions the authors drew. For example, showing that a stimulus will produce Stroop-like interference when presented outside the focus of attention may mean that the stimulus is processed automatically to some degree,

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[2]The concept of effort is often operationalized as dual-task interference (e.g., Logan, 1978, 1979) or as load effects in search tasks (e.g., Shiffrin & Schneider, 1977); the concept of autonomy is often operationalized as Stroop-type interference (e.g., Logan, 1980; Posner & Snyder, 1975).

but it does not mean that the stimulus is processed in exactly the same way without attention as with attention (i.e., it does not mean that the stimulus is processed completely automatically, see Kahneman & Treisman, 1984). Similarly, finding that processing is subject to load effects or dual-task interference may mean that the processing is not yet completely automatic, but it does not mean that processing is not at all automatic. The co-occurrence of Stroop-like interference and load effects or dual-task interference could mean that the processing is only partially automatic, which need not compromise the internal consistency of the concept of automaticity. Of the three sets of authors, Kahneman and Chajzyck (1983) were most sensitive to this possibility.

The interpretation of studies of co-occurrence of properties can also be challenged by viewing automaticity from a skills perspective. There is evidence that each of the properties of automaticity change more or less continuously as a function of practice. Solomons (1899) demonstrated long ago that speed increases more or less continuously with practice (see also Newell & Rosenbloom, 1981). Bahrick and his colleagues (Bahrick, Noble, & Fitts, 1954; Bahrick & Shelley, 1958), Logan (1978, 1979), and Neisser and his colleagues (Hirst, Spelke, Reaves, Caharack, & Neisser, 1980; Spelke et al., 1976) demonstrated that dual-task interference diminishes more or less continuously with practice. Shiffrin and Schneider (1977) and many others have shown that load effects in search tasks diminish more or less continuously with practice, and several investigators have shown that the power of a stimulus to produce Stroop-like interference increases as subjects become more practiced with the stimuli (e.g., Johnston, 1978; Schadler & Thissen, 1981).[3] All of these studies suggest that automaticity is relative, that performance changes in the direction of automaticity rather early in practice and keeps changing as practice continues. Indeed, there is no clear evidence that automatization ever becomes complete. The performance asymptotes that become apparent after relatively large amounts of practice could be ceiling or floor effects in the measurement of automaticity rather than the completion of automatization. LaBerge and Samuels (1974) made this point comparing accuracy and speed as criteria for learning (accuracy reaches asymptote long before speed does). There is no reason why their point cannot be extended to other measures.

The idea that automaticity is relative makes co-occurrence of properties quite difficult to assess. Each property has its own time-course of change with practice, and no current theory specifies how the different properties should be related at any arbitrary point in practice. Thus, Regan's (1981) finding that, after low levels of practice, Armenian letters produced load effects and Stroop-like interference suggests that Stroop-like interference begins with very little practice, whereas

[3] Developmental studies often show that Stroop interference first increases and then decreases as age and, presumably, experience with reading increase (e.g., Schadler & Thissen, 1981). This may seem contrary to the proposition that the power to produce Stroop interference increases with practice. However, it is important to remember that performance on the task that is interfered with (e.g., colour naming) usually speeds up as age and practice increase, so there is less time for interference to take effect.

load effects diminish rather slowly with practice.[4] Her data need not be interpreted as evidence against the internal consistency of the concept of automaticity.

Indeed, it is instructive to consider what assumptions must be made in order to interpret Regan's (1981) data as evidence against the internal consistency of the concept: It would seem that automaticity must be described as a dichotomous phenomenon to interpret her data as she did. That is, the phenomenon of automaticity consists of exactly two mutually exclusive states — completely automatic and completely nonautomatic — with Stroop-like interference and the absence of load effects identified with the completely automatic state on the one hand, and the absence of Stroop-like interference and the presence of load effects identified with the completely nonautomatic state on the other. Under these assumptions, her data suggest that the processing of Armenian letters occupies both states simultaneously, which is not internally consistent (i.e., the two states should be mutually exclusive). Indeed, her data indicate there is a lack of internal consistency somewhere. It seems, however, that the lack of consistency resides in the implicit assumptions about automaticity being a binary or polar-opposite phenomenon rather than in the concept of automaticity itself. If automaticity were assumed to be a continuum or a set of ordered states ranging from nonautomatic to automatic, Regan's data could be accommodated.

How, then, can the co-occurrence of the various properties be assessed, given the idea that automaticity is relative? Tests of co-occurrence are important because they allow the assessment of the internal consistency of the concept. However, if all of the properties change continuously with practice, possibly never reaching asymptote, how can co-occurrence be assessed? I suggest that co-occurrence can be assessed by determining whether the various properties change with practice in the direction of increasing automaticity. Thus, an increase in speed at the cost of increased dual-task interference would not be viewed as automatization, just as an increase in speed at the cost of increased errors is not viewed as an improvement in performance. If speed increased and dual-task interference increased over a reasonable large amount of practice (2 or 3 sessions, say), that would be evidence against the internal consistency of the concept of automaticity. To my knowledge, no such results have ever been reported, though many investigators have found internally consistent results (e.g., an increase in speed together with a reduction in dual-task interference: see Fisk & Schneider, 1983; Logan, 1978, 1979).

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[4] Regan (1981, Exp. 3) found that Armenian letters interfered with naming English letters even in subjects who were "totally unfamiliar with Armenian letters" (p. 191), which suggests there may have been a problem with the control condition against which she assessed interference. When the same control condition was included in a design in which the distracting letter matched or mismatched the target letter, the control condition was faster than both matching and mismatching conditions. Typically, a match between the target and the distractor produces facilitation and a mismatch produces interference (e.g., Miller, 1981; see also Posner & Snyder, 1975); the control condition should fall in between the matching and mismatching conditions. The fact that it didn't in Regan's Experiment 2 suggests that her control condition may have overestimated interference from totally unfamiliar Armenian letters in Experiment 3.

Note that a change in one property without a change in another property is not necessarily evidence against the internal consistency of the concept of automaticity. Such results could easily be produced by comparing performance over very small amounts of practice. Moreover, some properties reach asymptote before others (e.g., Logan, 1979), and a property that has reached asymptote should not be expected to change while another that has not yet reached asymptote continues to change.[5] What this means is that we must look carefully at the designs of experiments that test the co-occurrence of properties.

The idea of looking for co-occurring changes in properties of automaticity with practice seems less likely to produce evidence against the internal consistency of the concept of automaticity than the earlier idea of looking for simple co-occurrence of properties. I believe this is because looking for co-occurring changes is the more appropriate way to assess internal consistency; tests of simple co-occurrence seem to be biased toward finding evidence of inconsistency. Others may not be as convinced as I am, arguing that tests of co-occurring changes are biased in the opposite direction. If that is true, it may not be a bad thing. Automaticity is a relatively old concept in psychology, handed down from ordinary language where it has withstood the test of time. As such, it is probably worth keeping around for a while until we are dead sure that it is wrong. To mix metaphors, we don't want to throw the baby out with the bath water.

Automaticity and Multiple Resources

When the modern resurgence of interest in automaticity blossomed in the early 1970s, single-channel theories of attention were declining in popularity (e.g., Broadbent, 1958; Welford, 1952) and single-capacity theories of attention were gaining ascendancy (e.g., Kahneman, 1973; Posner & Boies, 1971). In that context, the process of automatization was viewed as a gradual withdrawal of attentional involvement in performance (e.g., LaBerge, 1973; Laberge & Samuels, 1974; Logan, 1978).[6] Since then, a new, *multiple resource* view of attention has come to dominate the field (e.g., Allport, 1980; Navon & Gopher, 1979; Wickens, 1980, 1984), which suggests a different perspective on automatization.

Acccording to a multiple resource view, performance depends on a number of

[5] The idea that different properties of automaticity reach asymptote at different points in practice may help resolve a troublesome issue in skill acquisition that was noted by Keller (1958) : The plateaus described by Bryan and Harter (1899) may capture the intuitions people have as they acquire skill, but they rarely appear in performance data. It is possible that plateaus represent different properties of automaticity reaching asymptote at different times, so that when people notice no further change in a property, they feel they have reached a plateau. However, when one property reaches asymptote, the others, including the one observed by the experimenter, may continue to change gradually (e.g., reaction time may continue to decrease after dual-task interference reaches asymptote, see Logan, 1979). Thus, plateaus may be experienced by the learner without appearing in performance data.

[6] The concept of automaticity has enjoyed a resurgence of interest since the ascendance of economic theories of attention (e.g., Kahneman, 1973; Navon & Gopher, 1979), but it need not be articulated in those theories (e.g., see Kolers, 1975). Automaticity is a natural phenomenon, not a deduction from economic theories of attention. Thus, challenges to economic theories of attention are not necessarily challenges to the concept of automaticity.

hypothetical mental entities called resources, each of which is limited in quantity. By hypothesis, different tasks may depend on different resources, and dual-task interference occurs only when the tasks share common resources. Thus, the interference a particular task produces will not be an invariant characteristic of that task; rather, it will depend on the nature of the tasks it is combined with. There is abundant evidence for this claim, which accounts for the current popularity of multiple resource theory (for reviews, see Wickens, 1980, 1984). For example, a task with visual input will suffer more interference from another task with visual input than from another task with auditory input (e.g., Treisman & Davies, 1973). Similarly, a task with manual output will interfere more with another task with manual output than with another task with vocal output (e.g., Logan, Zbrodoff, & Fostey, 1983).

What does automaticity mean in a multiple resource theory? A common practice is to restate the answer offered by single-channel and single-capacity theories: Automatization reflects a reduction in the amount of resources needed to perform a task (i.e., automatic processing is "cheap": see Navon & Gopher, 1979; Wickens, 1984). One problem with this view is the implication that a completely automatic process will take no resources at all, which is completely antithetical to the basic assumption of multiple resource theory; namely, that every task or process requires some resources. There is no language in multiple resource theory that would allow us to talk about processes that take no resources; they are nonentities as far as the theory is concerned.

It may be possible to get out of this difficulty by asserting that a process or task can never become completely automatic, so that a process or task will always require some small amount of resources (i.e., automatic processes may be "cheap but not free": see Navon & Gopher, 1979; Wickens; 1984). This hedge appears to be falsified experimentally by demonstrations of asymptotic effects of practice (e.g., zero slopes in search tasks, Shiffrin & Schneider, 1977; no dual-task interference, Spelke et al., 1976). However, these empirical asymptotes may reflect ceiling or floor effects in our measures of automatization rather than a limit on the degree of automatization itself. Thus, the hedge may neither be falsifiable nor verifiable by experiment, which makes it weak theoretically.

The idea that a task or process may always require some resources is reminiscent of the earlier suggestion that there may be no limit on the degree of automaticity a task or process can attain, insofar as they both imply that automatization may never be complete. However, the two positions are not necessarily the same. The former position suggests that there are severe limits on automatization that a task or process can never approach (i.e., a task or process can never require no resources), whereas the latter position suggests that there may be no limits that cannot be overcome (i.e., there may always be more to learn).

There is another major problem with the view that automaticity represents a reduction of the amount of resources required: Of which resources do automatic tasks and processes use less? This was an easy question to answer in the earlier single-channel and single-capacity theories because there was only one major resource to be considered (i.e., attention). In multiple resource theory, the problem is more difficult. One possibility is to argue that there is a single *executive* resource that presides over the others in the performance of every task (e.g., Broadbent, 1977; Logan, 1979; Logan & Cowan, 1984; Reason & Myceilska, 1982). Thus, a task requires less of the executive resource as it becomes automatic. However, this hedge raises another problem, which is to identify the executive resource and to separate its effects from those of its subordinates. There may be no single executive; different resources may assume executive control in different tasks. Also, the executive may require more than a single resource.

As before, there may be a lesson to be learned by taking a skills perspective on the problem. Skilled performers may be able to make their performance appear effortless, as if they were using fewer resources than novices, but that may not be the whole story. Most investigations of skill suggest that skilled performers do their tasks differently than do novices. In the terminology of multiple resources, they do not simply use fewer resources than novices; rather, they use different resources than novices. Several investigators have noted a shift in the composition of processes underlying a skill as that skill is acquired (e.g., Fleishman & Hempel, 1954; Jones, 1962; Murphy & Wright, 1984). For example, typists appear to shift from predominantly visual feedback at early stages of skill acquisition to predominantly kinesthetic feedback at later stages of skill acquisition (West, 1967).

Thus, the appropriate way to view automatization in a multiple resource theory may be as a shift in the kinds of resources that are used as practice progresses. Automatization may involve a reduction in one kind of resource, as Navon and Gopher (1979) and Wickens (1984) have suggested, but in addition, there may be a concomitant increase in the utilization of another kind of resource. No students of automaticity seem to have taken this position very seriously (e.g., see Logan, 1979), but several recent theories of skill acquisition have endorsed it (i.e., Anderson, 1982; Crossman, 1959; Newell & Rosenbloom, 1981; but see MacKay, 1982).

The idea that automatization may result in a shift in the resources used to perform a task has very interesting empirical implications.[7] For one thing, it

[7]The idea that automatization reflects a shift in the resources used to perform a task has interesting implications for questions of co-occurrence of properties of automaticity: It may be possible to observe an increase in dual-task interference over practice together with an increase in autonomy and a reduction in reaction time, which would suggest that the concept of automaticity is not internally consistent. However, there may be a general reduction in the amount of resources used as well as a shift in resources. The overall reduction in resources would result in an overall reduction in dual-task interference (i.e., for all concurrent tasks, whether they share the resources used in the original version of the task or the resources used in the automatized version). The shift in resources would result in an interaction between practice and dual tasks, with dual-task interference diminishing more rapidly for dual tasks that shared resources with the original version of the (automatized) task than for dual tasks that shared resources with the automatized version of the (automatized) task. Thus, the idea that automatization reflects a shift in resources need not necessarily predict results contrary to the assumption of co-occurrence. Whether or not such results would occur is an empirical question (and one that is well worth addressing).

explains why transfer from one concurrent task to another is often less than perfect (e.g., Logan, 1979) and why Shaffer (1975) found that skilled typists could shadow auditory input while typing visual copy without interference, but they could not type auditory input while shadowing visual input. A particular dual-task environment may encourage subjects to use a particular set of resources that may not be very useful in a different dual-task environment.

The implication is that automatization should result in very specific ways of performing a task, which should produce a rather narrow generalization gradient when transfer to other situations is tested. Indeed, this lesson has been lurking for several years in studies that demonstrate the importance of consistent mapping and, generally, consistent conditions of practice in the development of automaticity (e.g., Schneider & Fisk, 1982; Shiffrin & Schneider, 1977). These studies suggest that subjects do not become better at searching memory or searching visual arrays in general (hence the poor transfer to different mappings and the failure to develop automaticity with varied mapping); rather, subjects become better at searching particular arrays for particular targets, as if they are becoming more specialized in the way they use resources.

Possibly, there may be a general reduction in the involvement of an executive attentional resource with automatization, in addition to the proposed shift in the pattern of resources used to perform the task. The interesting thing is that these questions can be addressed empirically. It appears that a lot of important research remains to be done. I would suggest that this research would profit considerably if it were conducted from a skills perspective, taking into account the lessons learned from three-quarters of a century of research into the nature of skills.

Automaticity and Control

Many investigators suggest that automatic processes are difficult to control or are uncontrollable (e.g., Jonides, 1981; Posner & Snyder, 1975). Schneider and Shiffrin (1977; see also Schneider et al., 1984; Shiffrin & Schneider, 1977) are the most notable proponents of this position, drawing an explicit distinction between automatic and *controlled* modes of information processing. Others have followed in their footsteps so that the distinction between automaticity and control seems to have become part of contemporary jargon and appears in elementary textbooks.

The major evidence that automatic processes are uncontrolled is the Stroop effect in its various guises. In the Stroop effect, unattended dimensions of a stimulus interfere with the processing of the attended dimension(s), often despite subjects' best efforts to ignore them. The idea is that automatic processes are initiated by the presence of an appropriate stimulus, and they run on to completion once begun, despite subjects' efforts to inhibit them. When they are antagonistic to the required decisions or responses, as in most Stroop-like situations, they interfere with performance by typically increasing reaction time. Even stimuli presented outside the focus of attention can produce Stroop-like interference (e.g., Eriksen & Eriksen, 1974; Shiffrin & Schneider, 1977). Thus, the popular conception that automaticity and control are opposites appears to be well founded.

However, Stroop-type interference does not imply that the underlying automatic process is out of control, functioning in exactly the same way regardless of the subjects' intentions. Instead, Stroop-type interference suggests only that the automatic process becomes active enough to interfere with performance (i.e., it need not be beyond control to produce interference, see Kahneman & Treisman, 1984). Further, Stroop-like interference may be overinterpreted: People make few errors on the Stroop task, and there are few false alarms to stimuli presented outside the focus of attention (see Eriksen & Eriksen, 1974); the difficulty subjects experience in controlling responses to these unattended stimuli usually makes itself apparent as an increase in reaction time, which can often be rather small (i.e., less than 10%). In the context of continuous skills, such interference would be viewed as a minor perturbation.

The close relation between automaticity and skill suggests that automatic processes may not be difficult to control. Skilled performers are usually able to control their performance better than unskilled performers, even though their performance is likely to be more automatic. That is why we prefer to fly with experienced pilots rather than novices, why we feel more comfortable with experienced dentists and surgeons than with beginners, and so on. Indeed, there are formal demonstrations that skilled performance is very closely controlled: Long (1976), Rabbitt (1978), and Logan (1982) demonstrated that skilled typists have very close control over their typing, being able to inhibit high-speed typing within one or two keystrokes of detecting an error or an overt signal to stop. Similarly, Ladefoged, Silverstein, and Papcun (1973) and Levelt (1983) demonstrated that adult speakers, who are presumably skilled, have very close control over their speaking, being able to inhibit speech within a syllable or two of detecting an error or an overt signal to stop. Despite the close control, highly skilled activities such as speaking and typing are best characterized as automatic. They can be done very quickly, if need be, with little effort (cf. Hasher & Zacks, 1979; Logan, 1979; Posner & Snyder, 1975). It appears that the general belief that automaticity and control are opposites may be mistaken, or at least, overstated.

The contrast between automaticity and control may be an artifact of our usual style of theorizing in psychology rather than a theoretical necessity forced upon us by the data. Psychologists often characterize the phenomena they study as dichotomies (Newell, 1973). Thus, investigators who have avoided contrasting automaticity with control nevertheless contrast it with another binary opposite, such as effortful processing (Hasher & Zacks, 1979), strategic processing (Ratcliff & McKoon, 1981), deliberate processing (Anderson, 1980), or conscious processing (Posner & Snyder, 1975). Newell suggested that the strategy of treating phenomena as dichotomies was not likely to be productive scientifically. The skills perspective suggests that it may not even be appropriate in the context of research on automaticity. Like skill, automaticity is a dimension, and it can be studied profitably without treating extreme points on the dimension as if they were opposites.

FUTURE IMPLICATIONS

The discussion so far has suggested how current issues in automaticity might be informed, reformulated, or resolved by taking a skills perspective. In the remainder of the article, I would like to suggest some implications for future work on automaticity and skill that derive from an awareness of the close relations between the areas. The implications stem from two ideas: First, automaticity should be studied in a broader range of paradigms in order to capture the variety of ways in which it is important in skilled performance; and second, research on automaticity should take into account the continuous, cyclical nature of many skills, which is largely neglected in the current literature. A final implication that is explored is the possibility of studying practice effects in more detail, returning the phenomena of learning to centre stage in cognitive psychology.

Automaticity from a Skills Perspective

Perhaps the most important lesson students of automaticity can learn from students of skill is that automaticity occurs in a broad range of contexts. Most skills have automatic components, and the range of skills modern people are capable of performing is substantially broader than the range of paradigms in which automaticity is studied. Most studies of automaticity focus on three basic paradigms: search tasks (e.g., Schneider et al., 1984; Shiffrin & Schneider, 1977), Stroop tasks (e.g., Logan, 1980; Posner & Snyder, 1975), and concurrent tasks (e.g., Logan, 1978; Paap & Ogden, 1981). These paradigms are becoming well understood and have provided many insights into the phenomenon of automaticity, but they are limited. They tend to be discrete, with trials that typically last less than 2 seconds, and usually pains are taken to ensure that successive trials are independent of each other. They stand in marked contrast with most skills, which are often continuous and may contain sequential dependencies that take hours of experience to discover. Moreover, the typical search, Stroop, and concurrent-task paradigms are relatively simple; they can be learned to an accuracy criterion (LaBerge & Samuels, 1974) after a few moments of instruction. Possibly, the most serious difficulty in obtaining optimum performance is overcoming the boredom that sets in after a few hundred trials. This, again, contrasts markedly with typical skills. Skilled performers often enjoy the task they perform and have no difficulty maintaining motivation for long periods of time. Consider, for example, the dedication and perseverence shown by a person acquiring skill on a musical instrument or a video game.

I do not mean to imply that we should abandon search, Stroop, and concurrent tasks as paradigms for studying automaticity. Each paradigm provides a different perspective on automaticity, abstracting different properties of automaticity which we can study in detail. However, this does not imply that all of the details of each paradigm represent properties of automaticity. We should be aware of each paradigm's limitations and take care not to attribute problems with the paradigm to problems with the concept of automaticity (cf. Ryan, 1983).

It would be worthwhile supplementing the search, Stroop, and concurrent-task paradigms with paradigms that capture aspects of automaticity that make themselves apparent in complex skills. This was my intention in studying the inhibition of thought and action (e.g., Logan, 1983; Logan & Cowan, 1984). Perhaps other aspects of automaticity could be studied in vivo, and the results brought to bear on conclusions drawn from the simpler, abstracted laboratory paradigms. The recent work of James Reason (1984; Reason & Myceilska, 1982) on mental lapses and everyday errors is an important step in this direction.

Automaticity in Continuous Skills

One of the most salient differences between continuous tasks and the typical paradigms in which automaticity is studied is the preponderance of sequential dependencies in the former and the relative absence of them in the latter. Much of skill derives from learning to control and exploit the dependencies. Continuous tasks often allow performers to look ahead and anticipate future responses; skilled performers may anticipate more than the less skilled (e.g., Butsch, 1932; Poulton, 1957; Schmidt, 1968). Coarticulation phenomena in speech and typing represent a blending of anticipation with the constraints imposed by prior responses. For example, Rumelhart and Norman (1982) showed that sequential dependencies and context effects in keystroke timing can often by predicted from the interaction between the current position of the fingers on the keyboard and the intended (i.e. future) position(s). Few laboratory studies have tried to abstract pehnomena like these and investigate them in detail; most try to control them out of the picture. Recent studies of priming effects (e.g., Neely, 1977; Posner & Snyder 1975; Ratcliff & McKoon, 1981) and sequential effects in Stroop tasks (e.g., Lowe, 1979; Neill, 1977) are notable exceptions.

Sequential effects in skilled performance have interesting implications for independence from attention as a property of automaticity. Several theorists have suggested that automatic processes are independent of attention (e.g., Hasher & Zacks, 1979; LaBerge, 1973; Posner & Snyder, 1975), but automatic processing cannot be entirely independent of attention. This is obvious in continuous skills where the current focus of attention determines what the next input will be and, hence, what will be processed automatically. It has been demonstrated only recently in abstracted laboratory studies: Francolini and Egeth (1980) and Kahneman and Henik (1981) showed that Stroop interference depends on the spatial direction of attention. Similarly, Hoffman, Nelson, and Houck (1983) combined automatic detection with other signal detection tasks and found that automatic processing was affected by the way attention was directed spatially to the concurrent task. Recently Smith (1979), Smith, Theodore, and Franklin (1983) and Henik, Friedrich, and Kellogg (1983) showed that the priming effect of one word on the subsequent word depended on how the priming word was processed. This is particularly interesting because the priming effects, which may have been automatic, depended on the conceptual direction of attention rather than the spatial direction of attention that was manipulated in the previous studies.

The laboratory studies demonstrating dependence between attention and automaticity have had a large impact in their short history, partly because they seem to challenge the concept of automaticity. The challenge stems from the assertion that attention and automaticity should be independent, made by some recent theorists in discussing abstracted laboratory paradigms. This is not a necessary assumption in the natural language concept of automaticity or, indeed, in the picture of automaticity we get from skilled performance. There, automaticity is thought to work together with attention as "the hands and feet of genius" (Bryan & Harter, 1899, p. 375). Thus, it may be the theorists that are challenged rather than the concept or the phenomenon of automaticity.

Part of the reason for the impact of studies showing dependence between attention and automaticity, I believe, is that they represent a truer picture of the phenomenon of automaticity than do theories and studies that assert independence. Much important research remains to be done, both in abstracted laboratory experiments and in more natural situations.

Skill, Automaticity, and Practice

The last direction for future research I would like to discuss is studies of practice. Automaticity and skill are both produced by practice, and it is important both theoretically and practically to understand more about the conditions of practice that do and do not produce automaticity and skills. So far, it is clear that consistency of practice is important in producing automaticity (e.g., Logan, 1979; Schneider & Fisk, 1982) but other factors should be investigated. For example, Brickner and Gopher (1981) showed that subjects learned to perform two tasks together better if the priorities assigned to the tasks varied throughout practice than if they remained constant, possibly because varying priorities allows subjects to learn more about different ways to combine the tasks.

It would also be important to learn more about what is learned during skill acquisition and automatization. Recent thoeries of the acquisition of cognitive skills have begun to deal with this issue (e.g., Anderson, 1982; MacKay, 1982; Newell & Rosenbloom, 1981), but theoretical and empirical work on automaticity largely neglects it. Clearly, much important work remains to be done.

CONCLUSIONS

Automaticity and skill are closely related, in that automaticity is a component of skill, but they are not the same thing. Skills consist of metacognitive and declarative knowledge as well as automatic procedures. Automaticity and skill are also related in that both are produced by practice, which has implications for three major issues in current studies of automaticity: (1) Co-occurrence of properties. Researchers interested in the internal consistency of the concept of automaticity should look for co-occurrence of changes in the properties rather than co-occurrence of the properties themselves. All of the properties change as practice progresses, perhaps each at a different rate; thus, search for simple cooccurrrence seems arbitrary. (2) Multiple resources and automaticity. In multiple resource theories of attention, as in theories of skill acquisition, automaticity may refer to a qualitative change in the composition of resources recruited for the task rather than a quantitative reduction in the amount of resources used. In addition, there may be a reduction in the involvement of executive processes as practice continues. (3) Automaticity and control. The popular conception that automaticity and control are opposites may be overstated or entirely mistaken. Skilled performance is considered automatic and controlled at the same time, so automaticity and control cannot be opposites. Moreover, there are laboratory studies showing close control over automatic processes.

Finally, implications for future research are discussed. A skills perspective on automaticity suggests that (1) automaticity should be studied in a broader range of paradigms than the usual search, Stroop, and concurrent tasks, (2) the interaction of attention and automaticity in sequential dependencies should be studied more, both in the laboratory and in natural settings, and (3) the conditions of practice that produce automaticity and skill should be better understood. The final message to be taken from this article is that much important work remains to be done. Skill and automaticity are active topics for research, and both can benefit from an open exchange of ideas.

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