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Automaticity (488)

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HEADWORD

Automaticity

KEYWORDS

attention, consciousness, expertise, skill acquisition, Stroop effect

CONTENTS LIST

ARTICLE DEFINITION

Automaticity refers to the way we perform some mental tasks quickly and effortlessly, with little thought or conscious intention. Automatic processes are contrasted with deliberate, attention-demanding, conscious, controlled aspects of cognition.

ACKNOWLEDGEMENTS

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1. Introduction

Try to think back to when you first learned how to drive a car. Your primary aim was to steer the car clear of other vehicles, pedestrians, and trees – a difficult task by itself. But you also had to control the pressure applied to the accelerator pedal to keep within posted speed limits. You needed occasionally to apply the brake to obey traffic signals and to avoid plowing into the car in front of you. Added to this, if you first learned to drive a car with a manual transmission, you had to decide when to shift and then you needed to coordinate the complex movements involved in changing gears – releasing the accelerator pedal, depressing the clutch, shifting to the appropriate gear, carefully releasing the clutch while applying some gas. And you had to do this while continuing to pay attention to the road ahead. On top of that, you probably had to linguistically process the commands, pleas, and screams of the poor soul who (perhaps regrettably) agreed to teach you how to drive. You had to direct all your mental energies to controlling and coordinating the complex sequence of movements involved in safely driving a car. Trying to simultaneously steer, accelerate, brake, shift, and listen was an exceedingly difficult task.

Contrast this scenario with how you may be able to drive after many years of practice. On long trips, you find yourself daydreaming and may not even remember what happened during the last several uneventful miles of highway driving. Shifting gears becomes one smooth continuous action. Indeed breaking up this complex action into its component parts may require some deliberate thought – in fact, on my initial draft of the previous paragraph, I forgot that the first critical step in shifting was to release the accelerator pedal – this is something I have done thousands of times during my twenty years of driving cars with manual transmissions, but this basic action did not initially come to mind when I tried consciously to decompose the act of shifting gears. Experienced drivers use so few mental “resources” that some people can drink coffee, talk on a cellular phone, and groom themselves while driving at high speeds on a congested expressway. Things are fine until something unexpected happens – another distracted driver veers into their lane or someone stops very abruptly ahead – now those resources diverted to drinking, talking, and grooming are not available to take immediate action to avert a serious accident.

That effortless way that we perform the various components of skilled actions, like driving a car, is termed *automaticity*. Many routine daily events become so automatic that we may seem unconscious of them – how many times have I lathered my hair this morning, did I remember to put the freshly ground coffee in the coffee maker, have I checked my mailbox yet this morning? Literate adults read automatically – try not to read the billboards and signs that bombard you when driving through suburban commercial developments. When skilled at playing a musical instrument, reading musical notation, translating notes into finger and hand movements, controlling breathing and embouchure, are all automatized procedures, allowing the musician to focus on higher levels of musicality like style, phrasing, and coordination with the conductor and other musicians. Skilled professionals automatically execute complex tasks that demand years of training. Experienced radiologists may be able to tell automatically, at a glance, whether a patient has a benign growth or a malignant tumor. Experienced pilots control complex aircraft automatically. Landing a commercial jetliner in good weather is performed with nearly the same fluency as driving to the neighborhood grocery store. This automaticity allows the pilot to monitor for unexpected events – an unauthorized aircraft on the runway, an approaching flock of geese, an engine fire, or wind sheer – and be able to take corrective action immediately to avert potential disaster.

This article describes the properties that distinguish automatic processes from those that require conscious mental control, describes factors necessary for achieving automaticity, illustrates the effects of automaticity with some classic experimental paradigms, and describes some psychological models of the acquisition of automaticity.

2. Characteristics of automatic processes

A number of characteristics have been emphasized to distinguish *automatic processes* from those that require some kind of overt mental control, what have been referred to as *controlled processes*. Theorists disagree on what particular characteristics are most important for describing a process as being automatic, and disagree on whether some particular properties appropriately characterize automaticity at all. In addition, some theorists have argued that perhaps the concept of automaticity itself should be abandoned entirely since no cognitive process is ever truly automatic given most lists of critical characteristics. Automaticity is a current topic of active research in the cognitive sciences, and ideas of how to best characterize automatic processing are still evolving.

The aim of this section is to survey most of the various characteristics of automaticity that have been proposed. These characteristics, summarized in Table 1, will be elaborated upon below. These characteristics should certainly not be considered orthogonal dimensions of automatic processes because many of them may overlap in some respects.

- Automatic processes are *obligatory*. Given the presence of particular stimuli within particular contexts, automatic processes can execute without the conscious intention of the individual. Automatic processes seem to occur reflexively. Controlled processes require conscious intention to become initiated.

- For this reason, automatic processes are said to be *stimulus-driven*. Given the appropriate triggering conditions, automatic processes execute without intention. Controlled processes are intentionally initiated by the individual, often with the guidance of central executive processes.
- Automatic processes are often *rigid* and *stereotypic*. Controlled processes can be reconfigured to deal with novel events, allowing for a far greater degree of flexibility.
- Once initiated, automatic processes require *no monitoring*. They run to completion without any need for overt executive control. Controlled processes require monitoring, and distractions can lead to breakdowns in performance.
- Automatic processes are *free from dual-task interference*. Automatic processes are not influenced by other tasks that are executed concurrently. Controlled processes suffer from dual-task interference. It is often extremely difficult to perform more than one controlled process at the same time.
- Because automatic processes can execute simultaneously, they are said to be processed in *parallel*. Not only can independent automatic processes be executed in parallel, but the various component processes of a complex skill may overlap one another in a parallel manner. Controlled processes execute serially. They are processed one step at a time and cannot be processed simultaneously.
- Many automatic cognitive processes are *well-practiced*. Controlled processes may be novel or less practiced.

- Automatic processes often characterize *expert* performance. Controlled processes often characterize novice performance.
- Because automatic processes can be performed in parallel without conscious monitoring, automatic processes are often *fast* compared to controlled processes.
- Automatic processes seem *effortless*. Controlled processes require mental effort.
- Automaticity is often discussed in the context of consciousness. Automatic processes may be *unconscious*. Controlled processes are conscious.
- Automaticity is also often discussed in the context of attention. Automatic processes may require *no attention*. Controlled processes do require attention.

3. Factors necessary for automatic processes

Some processes may be automatic because the human brain is equipped with special-purpose neural mechanisms for carrying out certain critical aspects of perception and cognition. Such automatic processes are obligatory because a specialized neural "module" operates autonomously, triggered by particular stimulus events in the environment. These are hard-wired mechanisms, making them rigid and stereotypic. Because these modules operate independently, they are not influenced by other concurrent processes operating within other parts of the brain, they do not require monitoring, they operate unconsciously, and they require no overt deployment of attentional resources.

Let us illustrate an example of an automatic process that may reflect the operation of one such hard-wired perceptual mechanism. Search for a yellow **X** in each panel of Figure 1. The target automatically "pops out" from the distractors in the left panel but an active search is required to locate the target among the distractors in the right panel. In the left panel, the yellow **X** differs from the red **X**'s by a single feature, but in the right panel, the yellow **X** differs from the yellow **O**'s and red **X**'s by the particular combination of color and form features. Salient singleton features are thought to automatically pop out because of the way early stages of the visual system process elementary visual information. Indeed visual search tasks have often been used to distinguish automatic, preconscious processing of elementary visual features from the more high-level, attention-demanding processing of conjunctions of multiple visual features necessary for object recognition. Similarly we may also automatically notice other kinds of perceptual events such as abrupt onsets of visual stimuli (a flash of lightning), auditory stimuli (a clap of thunder), or somatosensory stimuli (a crawling insect), because our perceptual systems may be hard-wired to automatically process sudden unexpected changes in the environment. So some aspects of perception and cognition may be automatic, and truly reflexive in nature, because there exist special-purpose neural mechanisms that operate autonomously, below the level of conscious awareness and control.

Clearly there do not exist innate hard-wired mechanisms for reading a book, driving an automobile, or flying an airplane. Yet people can become automatic at the elements of these tasks with sufficient practice. Therefore, a great deal of automaticity must be learned. How can a process go from being one that requires overt cognitive control to one that is automatic? And are there limitations on what kinds of tasks can become automatized?

For most aspects of human cognition that can become automatized, no one achieves automaticity without a great deal of practice. But some tasks may become automatized more quickly that others. Clearly a simple task may be automatized more quickly than a complex task. Some real-life tasks may take only a few hours of practice to become automatized. Others require many years of training. But complexity is not the only factor, nor the most critical factor in determining how rapidly a task can become automatized.

To illustrate, let us consider another example of a search task that has been used to study the development of automaticity. The visual display can contain between one and four letters (call this variable the display size, D). You can be asked to search for between one and four possible target letters (call this variable the memory set size, M). The task is to decide whether a target is present or absent in each display as quickly as possible without making any errors. The time to make a correct response will be recorded. A display size of one (D=1) and a memory set size of one (M=1) is a relatively easy search. As shown in the top of Figure 2, if the target is an **X**, the "search" is simply a matter of deciding whether the single presented letter on each display is an **X** or not. As the number of items in the display is increased, the task gets harder, and as the number of items in the memory set increases, the task gets harder. As shown in the bottom of Figure 2, suppose I tell you that the target memory set is now **T**, **L**, **Z**, and **V** (M=4). Each display will contain four letters (D=4) and you must decide if any of those four letters is one of the four target letters in the memory set. This search is quite hard. To accomplish this task, people generally search through each item in the display one at a time and compare it with each item in memory one at a time until a target is found. As such, search times increase systematically as a function of both the display size and the memory set size. This is a slow, deliberate, attention-demanding, serial search process.

Can this controlled search become automatized through training? Imagine that the set of targets and distractors changes throughout training such that a target on one trial may be a distractor on another trial. In such *varied mapping* conditions, it is very difficult, if not impossible, for the search task to ever become automatized, even with extended practice over several weeks. So practice by itself is not guaranteed to produce an automatic process.

Instead imagine that the set of targets and distractors remains consistent, such that the targets must be drawn from one set of letters and the distractors must be drawn from a different set of letters, and this differentiation is maintained throughout the entire course of training. In such *consistent mapping* conditions, automaticity can be achieved with practice. Indeed after extended practice, the time to search for targets does not vary with display size or memory set size. That is, a target pops out from the display much like the color pop-out shown in the left panel of Figure 2. But this is a learned automaticity, not a hard-wired one. This automaticity is immune to dual-task interference. This automaticity is rigid and inflexible in that switching to a varied mapping condition causes the search to revert back to a slow, deliberate, attention-demanding, serial process. Moreover, switching targets to distracters and distracters to targets causes performance to become even worse than it was before any training whatsoever, and it takes a long time to "unlearn" the original automatization of target searches. So one important criterion for developing automaticity is that there is a consistent mapping between stimuli and responses. This may be one reason for the stimulus-driven nature of much of automatic processing.

4. Stroop interference and other related measures

A different manifestation of automaticity can be seen in the classic Stroop effect. Named after John Ridley Stroop, the psychologist who developed it as part of his doctoral dissertation in the 1930's, the Stroop task has been used in thousands of experiments to study automaticity. First, find a clock with a second hand. Now, time how long it takes you to *name the ink color* of the words in the first column (i.e., BLUE, RED, PURPLE, etc.) – name the ink color, don't read the words. Next, time how long it takes to name the ink colors in the second column (i.e., RED, BLUE, ORANGE, etc.). And then do the same with the third column (i.e., PINK, RED, YELLOW, etc.). In all cases, try to respond as quickly as possible without making errors.

The classic Stroop interference effect is that the identity of the word can have a large effect on the speed of color naming. In the first column, the words themselves have no color association. In the second column, each word is congruent with its ink color, such as "red" in RED ink or "green" in GREEN ink. People are generally a bit faster to name the colors in the second column (congruent condition) than to name the colors in the first column (control condition). In the third column, each word is incongruent with its ink color, such as "red" in GREEN ink or "blue" in YELLOW ink. People are generally far slower to name the colors in the third column (incongruent condition) than to name the colors in the other columns. In the original paper by Stroop, subjects took nearly twice as long to name colors in the incongruent condition than the control condition, a finding that has since been replicated thousands of times across numerous experimental variations. Even without a stopwatch, you surely found naming ink colors in the third column quite difficult and perhaps a bit frustrating. This is the fundamental Stroop interference effect.

Stroop interference is not simply caused by having an incongruency between words and their ink color. Time how long it takes you to *read the words* in the first column of words in Figure 3 (i.e., CARD, ZOO, DIVIDE, etc.). Then time how long it takes to read the words in the second column (i.e., RED, BLUE, ORANGE, etc.). Then do the same with the third column (i.e., GREEN, PINK, BLUE, etc.). Ink color has little or no effect on the speed of reading words. Even for color words like “red,” the speed of word reading is not influenced by whether the word “red” is written in RED ink or GREEN ink.

Stroop interference is asymmetric. In the incongruent condition, words interfere with color naming but colors do not interfere with word reading. One acknowledged explanation for this is that word reading is a more highly automatized process than color naming. Word reading happens rapidly and effortlessly, without conscious intention, and cannot generally be suppressed. Naming colors requires more attention, conscious intention, and effort. Even when the task is to name the colors, and to ignore the words, word reading happens anyway, automatically, and can interfere with color naming.

The Stroop effect is not limited to interference of word reading on color naming. Figure 4 shows incongruent conditions from three variants of the Stroop task. In the first column, the task is either to read the digits (i.e., 4, 3, 5, etc.) or to count the number of digits (i.e., THREE, FIVE, FOUR, etc.). Reading digits is more automatized than counting, so digit identity interferes with counting, but the number of digits does not interfere with digit naming. In the second column, the task is either to read the spatial terms (i.e., “left,” “above,” “below”, etc.) or to specify the location of the term with respect to the central cross (i.e., RIGHT, BELOW, ABOVE, etc.). Word identity interferes with specifying spatial locations, but not vice versa. Finally in the third column, the task is either to read the animal name (i.e., “cow,” “frog,” “cat,” etc.) or to name the animal (i.e., BIRD, DOG, FISH, etc.). Word identity interferes with object naming, but not vice versa.

The classic case of Stroop interference is thought to occur because word reading is more automatic than color naming. If automaticity can be achieved through training, might it be possible to influence the direction of Stroop interference by manipulating practice with color naming? In principle, it should be possible to have color names interfere with word reading if color naming has been sufficiently practiced. But even with practice, it is extremely difficult to overcome the great prior advantage of word reading over color naming.

Instead imagine that you have just memorized that the symbols shown in Figure 5 are glyphs in some ancient language for the concepts blue, yellow, green, and red, respectively. The glyphs can be filled with various colors, creating congruent stimuli (e.g., “blue” glyph in BLUE) and incongruent stimuli (e.g., “red” glyph in YELLOW), as illustrated in the figure. When asked to name the color of the glyph, color naming is not influenced by the identity of the glyph, but when instead asked to name the glyph, glyph naming is strongly influenced by the color of the glyph. Because color naming is much more automatized than glyph naming, color interferes with glyph naming, but not vice versa. Now imagine that you are trained on glyph naming for several weeks, causing glyph naming to become more automatized than color naming. The direction of Stroop interference now reverses. Glyph identity interferes with color naming, but not vice versa. Results such as these suggest a continuum of automaticity with the direction of Stroop interference a potential marker for which cognitive process is more automatized.

5. Models of the acquisition of automaticity

Resource theories are based on the intuitive notion that people seem to have a limited amount of mental “energy” that can be allocated to performing various tasks. Controlled processes require a certain amount of these limited mental resources whereas automatic processes do not. Automatic processes are fast because they are not limited by available resources. Automatic processes are effortless because mental “effort” is proportional to the amount of resources needed to execute a process. Automatic processes are free from dual-task interference because they do not have to compete for the limited pool of resources. Automatic processes are obligatory because they do not need to wait until resources have been specifically allocated for their execution. The development of automaticity is viewed as a fundamental change in a process that makes it go from a resource-demanding controlled process to a resource-free automatic process. One criticism of resource theories has been that the learning mechanism by which processes reduce their resource demands is generally unspecified.

Another problem for resource theories is that complex patterns of interference have sometimes been observed. Some tasks interfere with one another, others do not. To deal with this complexity, some theorists have proposed that there may be multiple pools of mental resources. As an analogy, we could imagine that some processes consume electricity, other processes consume gasoline, and others consume coal. Any time two tasks interfere with one another, they must be dipping from the same pool of limited resources. While intuitively appealing, *multiple resource theories* have been criticized as being inherently untestable assertions. Any complex pattern of task interference effects is explained post hoc by positing multiple pools of resources.

Instead of viewing resources as mental energy that is allocated to different tasks, resources may instead be conceptualized as specific processing components of the cognitive system that different tasks may need to share. As an analogy, we could imagine a mental toolbox, with some tasks requiring a screwdriver, others requiring a hammer, and others a saw. When two tasks need to use the same tool, they have to wait their turn. For example, working memory is limited. To the extent that two tasks both store information in working memory, they may interfere with one another. There is evidence for multiple modality-dependent working memory systems for verbal, spatial, and object information, so complex patterns of interference may be the result of different tasks placing demands on different working memory systems. To the extent that an automatic process is divorced from its reliance on working memory, it will not interfere with other processes that demand those limited processing resources.

In an extreme case, there may be some central process that must be shared by all aspects of cognition that require selection among competing responses, what has been termed a *central bottleneck theory*. All tasks can be decomposed into a series of processing stages that extend from stimulus to response. Bottleneck theory posits that a particular one of these stages, that responsible for selecting among competing responses, can only be dedicated to one task at a time. All other stages prior to and subsequent to the response selection stage may proceed in parallel, but only one process can access response selection – other processes must wait. According to this theory, no cognitive process, no matter how highly practiced, can ever become truly automatic because all processes must share the limited response selection resource.

Our discussion of the Stroop effect should convince you that automaticity is not an all-or-none phenomenon. Word reading interferes with color naming because word reading is more automatic than color naming. But color naming interferes with shape naming because color naming is more automatic than shape naming. But with training, shape naming interferes with color naming because shape naming is now more automatic than color naming. It is not clear how a resource account could explain these asymmetric interference effects nor how the direction of interference effects can be modulated by training. *Strength theories* represent learning in terms of the strength of association within pathways from particular stimuli to particular responses. Such theories have been implemented within a variety of frameworks from production systems to connectionist networks. The development of automaticity is seen as the strengthening of particular associations – be they production rules or connection weights – as a function of experience. Where these pathways intersect, interference can be observed. Stronger pathways interfere more with weaker pathways, leading to asymmetric interference effects.

Finally *instance theories* proposes a different account of the development of automaticity. Controlled processes are the result of the execution of some explicit algorithm whereas automatic processes are the result of memory retrieval. The development of automaticity is caused by a transition from algorithm to retrieval. When first engaged in some task, people may use an algorithm or rule to execute that behavior. For example, when first learning to add single digits, children typically adopt a strategy of starting with one of the digits and counting the requisite number of additional digits to generate the answer. Instance theory equates automaticity with memory retrieval. With experience, children (and adults) just remember that 2+2 equals 4 without needing to explicitly count. Automatic processes are fast because memory retrieval is fast. Automatic processes are obligatory because memory retrieval is obligatory. Automaticity is effortless because memory retrieval seems effortless, especially compared with the execution of a multi-step algorithm. Automatic processes are free from dual-task interference because a single memory retrieval offers less opportunity for interference than a multi-step algorithm.

Execution of the algorithm and memory retrieval are assumed to take place concurrently, racing against one another to completion. The winner of the race determines what response is made. Early in learning, the algorithm is used because it completes before memory retrieval can finish (or because no memories can be retrieved). The development of automaticity is caused by the obligatory encoding of stimuli and responses in memory. As more memories of solutions are stored, memories can be retrieved more quickly. Thus, with experience, memory retrieval can eventually complete before the algorithm can complete. Consistent mappings are important because they yield consistent information from memory; varied mappings yield conflicting information from memory.

6. Summary

Automatic processes are the autopilots of human cognition. They seem to execute outside our awareness and without our conscious control. They seem to execute quickly, and we may be entirely unaware of the steps involved in their execution. They can execute while we are doing other things at the same time. Some processes are automatic because our brains have evolved special-purpose mechanisms that respond without our conscious intention, and even sometimes against those intentions. Other processes can become automatic because of our experiences. Automaticity can be learned. But automaticity can be achieved only under certain circumstances. It may well be that some processes may just never become automatic, regardless of how much experience a person has had. The concept of automaticity is intimately tied with concepts of attention, consciousness, learning, and memory. Some research aims to relate attention and automaticity, with some attempts to relate both to the far more elusive concept of consciousness. Other research aims to relate the development of automaticity to what we know about learning and memory more generally, examining how they all manifest themselves across the full spectrum of human cognition.

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GLOSSARY

Attention	The concentration of mental resources on particular physical or mental events.
Consciousness	The explicit awareness of particular physical or mental events.
Consistent Mapping	Responses associated with particular stimuli are consistent across trials.
Dual-task	A situation where more than one task is executed at the same time.
Expertise	The manifestation of exceptional abilities or skills in some domain.
Interference	The execution of one task is made slower or less accurate by the simultaneous execution of another task.
Parallel Processing	Two processes are performed at the same time.
Resources	Cognitive mental energy or component cognitive processes that are allocated to particular tasks.
Serial Processing	Two processes are performed in strict sequence.
Skill Acquisition	The process of learning a complex task composed of multiple components.
Varied Mapping	Responses associated with particular stimuli are inconsistent across trials.

Table 1. Some proposed characteristics of automatic and controlled processes.

Automatic Processes	Controlled Processes
obligatory	intentional
stimulus-driven	executive-driven
stereotypic	reconfigurable
rigid	flexible
no monitoring	monitoring
no dual-task interference	dual-task interference
parallel	serial
well-practiced	novel
expert	novice
fast	slow
unconscious	conscious
no attention	attention
effortless	effort

ILLUSTRATIONS

Figure 1. Find the yellow **X**. The left panel illustrates a feature search task for which the target automatically pops out from the field of distractors. The right panel illustrates a conjunction search task for which the target must be actively searched with deliberate shifts of attention.

Figure 2. Illustration of search task that manipulates display size (D) and memory set size (M). The top search has a single target (M=1) and a single display item on every trial (D=1). The bottom search has four possible targets (M=4) and four display items on every trial (D=4). The task is to detect a target as quickly as possible without making errors.

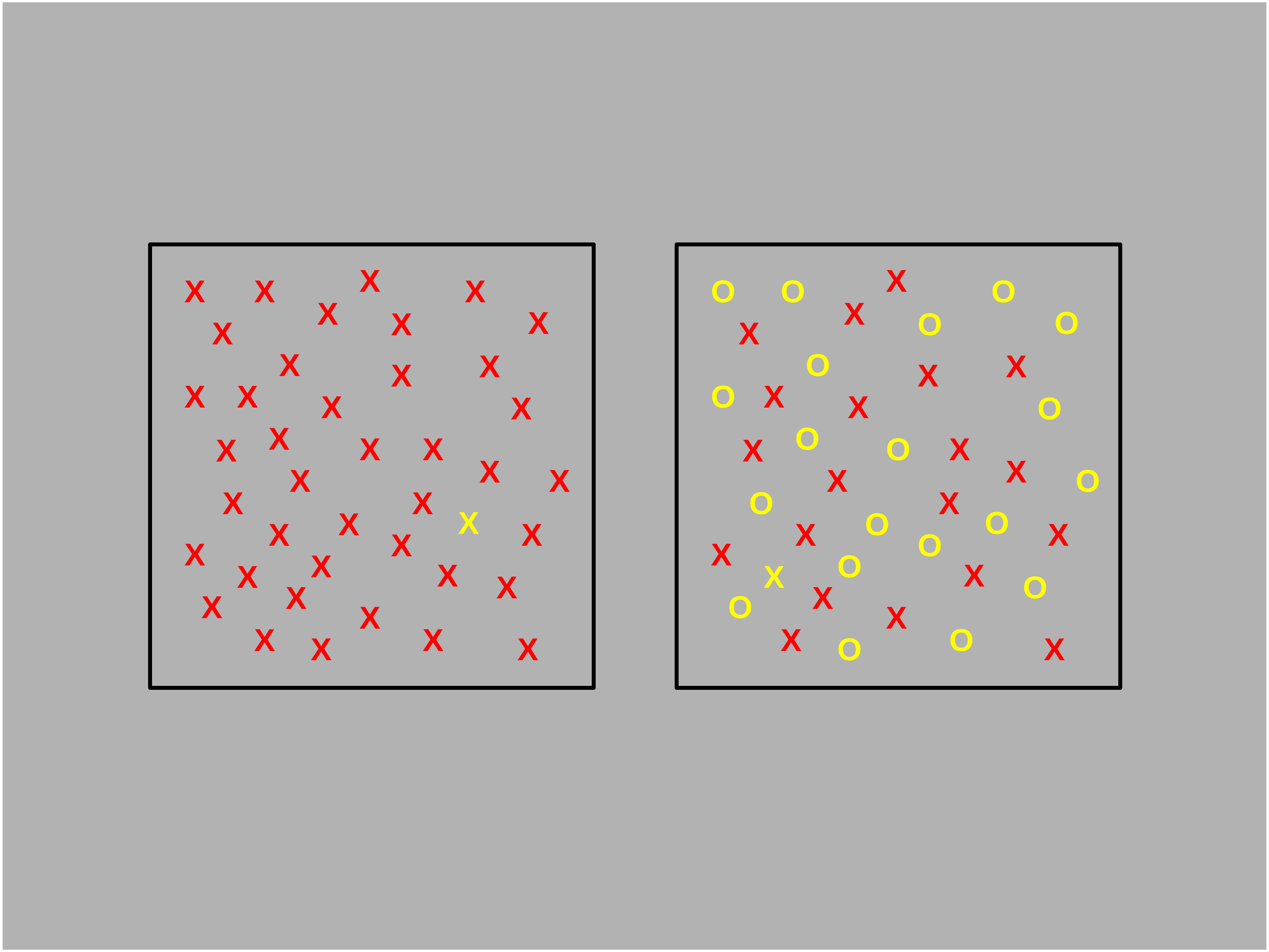
Figure 3. Demonstration of the Stroop task. Using a stopwatch, separately time how long it takes to *name the color* of each printed word in column #1, column #2, and column #3. Then separately time how long it takes to *read each word* in column #1, column #2, and column #3. Column #1 is a *control condition* in which the word and the color bear no relationship. Column #2 is a *congruent condition* in which the word and the color match. Column #3 is an *incongruent condition* in which the word and the color mismatch.

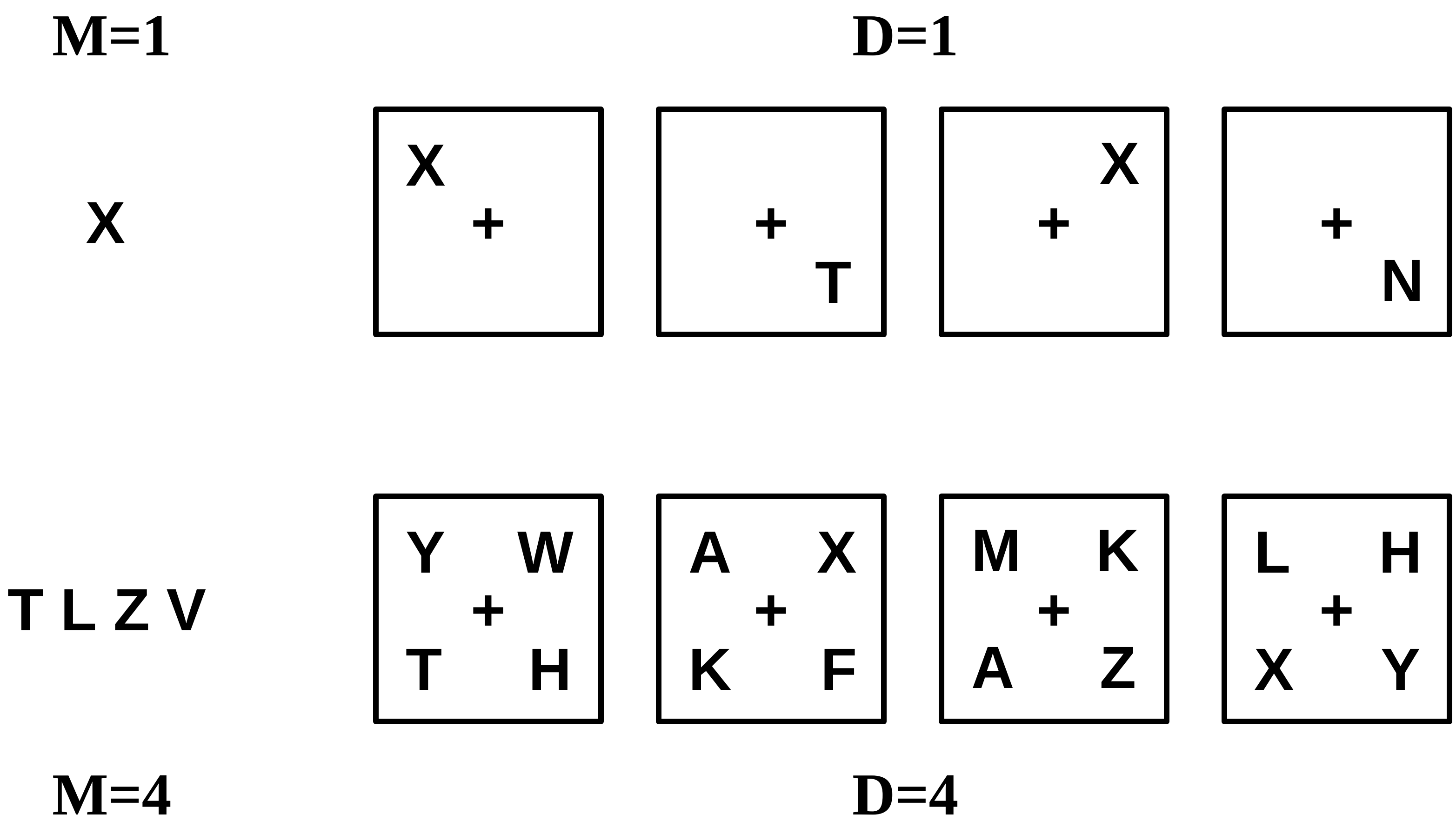
Figure 4. Illustration of incongruent conditions from three variants of the Stroop task. In column #1, you either name the digit or count the number of digits. In column #2, you either read the word or describe the spatial position of the word with respect to the central cross. In column #3, you either read the word or name the picture.

Figure 5. Illustration of novel stimuli used to manipulate the direction of Stroop interference through training. Each shape (glyph) is associated with one of four color names that must be learned. Each shape can also be filled with one of four colors. Subjects either name the shape (“blue,” “yellow,” “green,” or “red”) or name the color of the shape (RED, GREEN, BLUE, or YELLOW). Early in training, color interferes with shape naming. Later in training, shape interferes with color naming.

INFORMATION ON WORD PROCESSING PACKAGE USED

Microsoft Word 2000




M=1
D=1
X
X +
+ T
+ X
+ N
T L Z V
Y W + T H
A X + K F
M K + A Z
L H + X Y
M=4
D=4

#1	#2	#3
card	red	green
zoo	blue	pink
divide	orange	blue
fish	green	orange
card	pink	purple
friend	blue	yellow
drill	orange	green
card	yellow	blue
search	blue	red
drill	purple	yellow
divide	red	green
zoo	pink	blue
friend	green	pink
fish	yellow	orange
search	green	green
card	blue	red
drill	pink	purple

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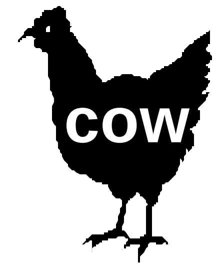
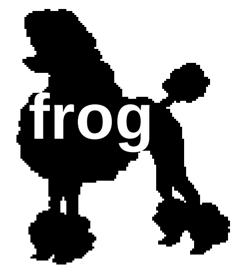
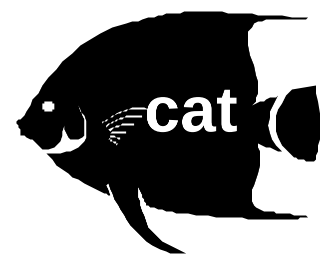
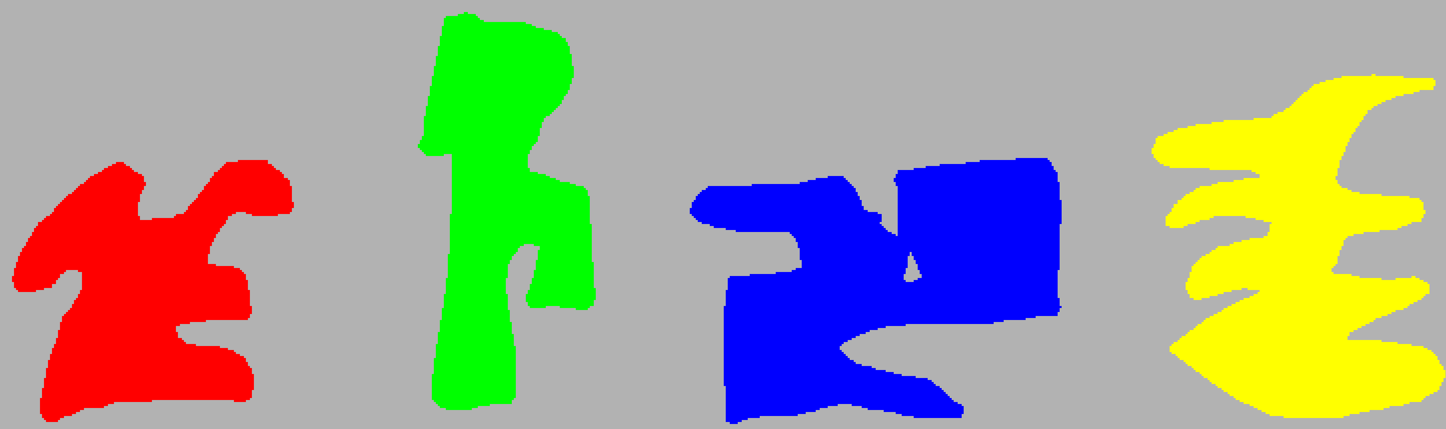
4 4 4	+ left	
3 3 3 3 3	+ above	
5 5 5 5	below +	



“blue” **“yellow”** **“green”** **“red”**