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21	Complex tasks across fields such as aviation, military, and healthcare require	21
22	operators to develop highly skilled and automatic levels of performance in response	22
23	to critical stimuli in the environment. This research extends the findings from the	23
24	dual-process theory of automaticity by considering the effects of two aspects in	24
25	a complex visual search task: the stimulus mapping and the response mapping.	25
26	In realistic visual search tasks, targets are often defined by a combination of cues	26
27	needed for search (e.g., altitude and speed), and responses are often diverse for	27
28	the same stimulus (i.e., destroying a target with two different weapons). Results	28
29	from our experiments indicate that variability of mapping, at both the stimulus and	29
30	the response sides, results in decreased performance and higher detection time.	30
31	When all the cues were variably mapped, performance deteriorated compared to	31
32	situations where at least one of the cues was consistently mapped. These results	32
33	have implications for designing complex visual systems and training individuals	33
34	in their use.	34
35		35
36		36
37	Introduction	37
38		38
39	One of the key contributions to the theoretical development of automaticity is the	39
40	dual-process theory (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977).	40
41	A classic finding from this theory is that automatic processing develops with	41
42	extended practice when targets are consistently mapped (they are always targets	42
43	and never appear as distractors). Such automatic processing is assumed to be fast	43
44	and parallel, requiring little attention or awareness. Thus, performance under	44

1 automatic processing is unaffected by workload. On the other hand, under varied 1
2 mapping conditions wherein stimuli may be targets in one instance but distractors 2
3 in another, performance occurs under controlled processing, which is voluntary, 3
4 serial, requires attention, and is significantly affected by workload. 4

5 Several complex tasks require participants to develop highly skilled and 5
6 automatic levels of performance to achieve fast and accurate responses to critical 6
7 stimuli in the environment. In visual search tasks ranging across fields such as 7
8 aviation, military, and healthcare, automatic detection processes are relevant 8
9 to situations such as a pilot detecting the presence of an enemy aircraft among 9
10 friendly aircrafts, a physician detecting the presence of a tumor in x-rays, or a 10
11 luggage screener detecting the presence of a hidden weapon among objects in 11
12 passenger luggage. The development of automaticity is particularly important for 12
13 these complex visual search tasks, because time pressure and workload may make 13
14 these tasks more difficult to perform in the absence of practiced skills. 14

15 The general guidelines for the design of these tasks drawn from the dual-process 15
16 theory of automaticity (Schneider and Shiffrin, 1985) are that optimal detection 16
17 and response times can be obtained by keeping targets consistently mapped. 17
18 In real-world complex tasks, however, it is hard to determine how to achieve 18
19 consistent mapping. Real-world tasks are replete with multiple and heterogeneous 19
20 stimuli, often requiring that we make decisions based on varied or inconsistent 20
21 conditions. For example, in the field of military aviation, pilots must be able 21
22 to distinguish the attributes of friendly aircrafts from those of enemy aircrafts 22
23 in order to select the appropriate response. The nature of visual search is often 23
24 *conjunctive*: successful detection depends on the combination of multiple cues. 24
25 For example, the detection of an enemy aircraft may depend on several cues such 25
26 as size, color, model, altitude, and speed, and it may be classified as belonging to 26
27 one of multiple categories of targets (e.g., very aggressive, moderately aggressive, 27
28 minimally aggressive). Also, the responses available for a target in these tasks are 28
29 varied. For example, an enemy aircraft may be tackled with multiple actions such 29
30 as 'ignore,' 'attack,' or 'destroy.' 30

31 Our goals in this research are to test the dual-process theory of automaticity 31
32 in a complex visual search task and to determine how the consistency of mapping 32
33 provides guidelines for the design of visual targets and responses. First, we discuss 33
34 stimulus and response mappings and the characteristics of complex visual tasks. 34
35 Next, we present two experiments to test the extent to which consistency of 35
36 mapping is needed in both the stimulus and the response. Finally, we discuss the 36
37 results of the experiments and the implications for design and training. 37

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40 **Stimulus and Response Mappings** 40

41 41

42 The complexity of visual search tasks can be determined by mapping the stimulus 42
43 and mapping the response. Traditionally, experiments demonstrating the dual- 43
44 process theory of automaticity used simple targets to demonstrate mapping; targets 44

1 are often defined by one visual cue. For example, Shiffrin and Schneider (1977) 1
2 used letters or numbers as the targets to be consistently mapped throughout their 2
3 experiments. In this research we use more complex visual targets defined by more 3
4 than one visual cue and by the combination of multiple cues. Also, traditional 4
5 experiments demonstrating the dual-process theory have used one response type 5
6 to indicate the detection of a target. For example, pressing a space bar upon finding 6
7 a letter on the screen. Again, in the real world the response modes are not that 7
8 simple, and in this research we used varied responses after the detection of the 8
9 visual target. 9

10 Thus, the concept of *consistency of mapping* from the dual-process theory 10
11 of automaticity can be defined in multiple ways in complex visual search tasks: 11
12 stimulus consisting of multiple cues (*conjunctive search consistency*) and multiple 12
13 responses (*consistency of responding*). These two types of consistency have been 13
14 previously identified in the literature of automaticity in generic task contexts. 14
15 For example, Fisk and Schneider (1984) investigated whether both consistency 15
16 of attending and responding (i.e., total task consistency) are necessary for the 16
17 development of automatic detection in a memory task. They found that performance 17
18 was better when stimulus mapping was consistent, but consistent response mapping 18
19 had a negligible processing benefit in their studies. They concluded that response 19
20 mapping was not necessary for the development of automatic processing and that 20
21 response mapping was less crucial for skill acquisition than stimulus mapping. 21

22 Similarly, Kramer, Strayer, and Buckley (1991) showed a benefit for consistent- 22
23 attending conditions rather than for varied-attending conditions with practice, but 23
24 no interaction with response mapping was present. They concluded that consistency 24
25 of responding was not necessary for the development of automatic detection and 25
26 that the processing costs of inconsistent responding were small. 26

27 Past findings indicate that total task consistency (both consistency of stimulus 27
28 and response mappings) is not vital for the development of automatic processing 28
29 (Durso, Cooke, Breen, and Schvaneveldt, 1987; Fisk and Schneider, 1984; Kramer, 29
30 et al., 1991). However, we believe that consistency in stimulus and response will 30
31 be important in tasks that are more complex than those used in past research. The 31
32 reason for this can be illustrated with the following example. In the military field, 32
33 soldiers often face situations where they need to choose a course of action based 33
34 on the perceived severity of the threat posed by an enemy aircraft. Specifically, 34
35 they may have to decide whether to use guns, bombs, or lasers to attack the enemy 35
36 depending on whether the hostile aircraft needs to be destroyed, captured, or 36
37 merely ‘frightened away.’ The challenge in a situation such as this arises from the 37
38 fact that an enemy aircraft might appear similar to friendly aircrafts on more than 38
39 one occasion and the required response varies depending on the pilot’s assessment 39
40 of the situation at hand. The need to distinguish targets defined by conjunctive 40
41 cues and then to respond to a stimulus in multiple possible ways poses a significant 41
42 challenge to operators in complex systems. These are the characteristics we defined 42
43 in the Radar task used in two experiments. 43

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45

1 The Radar Task

2
3 Most automaticity research involves simple and static tasks (items to be identified
4 do not change in time and space), but in the experiments presented in this paper we
5 used a complex visual search task with real-world counterparts called Radar. The
6 Radar task is a single-user visual search and decision making task in which the
7 goal is to detect and eliminate a hostile enemy aircraft by selecting an appropriate
8 weapon system. Radar is similar to military target visual detection devices, in
9 which a moving target needs to be identified as a potential threat and a decision
10 is made on how to best tackle the target under time constraints. The development
11 of this task was inspired by the theatre defense program (Bolstad and Endsley,
12 2000) and the task has been used in other research for automaticity (Gonzalez and
13 Thomas, 2008) and training (Young, Healy, Gonzalez, Dutt, and Bourne, 2008).
14 The Radar task has two components: (1) visual search and (2) decision-making.
15 Due to the nature of the two experiments reported in this chapter, only the visual
16 search component of Radar is described here. In the methods section of each of
17 the experiments, we explain how this component of Radar was adapted to address
18 the two manipulations studied here. A complete description of Radar including the
19 decision-making component can be found in Gonzalez and Thomas (2008).
20 The visual search component of Radar requires the user to memorize a set of 20
21 targets and then look for the presence of one or more targets in consecutive radar
22 grids. In each of the radar grids, four blips appear in the four corners of the screen:
23 Northwest, Northeast, Southwest, and Southeast (see Figure 5.1). The blips move
24 from the four corners to the center of the screen, where they collide and disappear.
25 During this time, the player needs to determine if a member of the memory set is
26 present or not on the Radar screen. That is, the detection of an enemy aircraft must
27 occur before the blips collide in the middle of the grid. A target threat may or may
28 not be present among a set of moving blips that represent incoming aircrafts. We
29 manipulated the stimulus mapping, workload (the number of items memorized and
30 the number of items on the radar screen), and the time constraints (called the frame
31 time, measured as the time taken by the blips to collide in the middle of the grid).

34 Experiment 1: Conjunctive Search Consistency

35
36 This experiment tested the dual-process theory of automaticity when targets are
37 formed by the conjunction of two cues in Radar. Rather than using one cue (symbol
38 type), we used two cues (symbol type and color) to characterize the targets. Each
39 of these cues was either consistently mapped (the target was characterized by the
40 same cue throughout practice) or variably mapped (the targets were characterized
41 by some cues in some trials and different cues in other trials). We also used a
42 workload variable—memory-set size (the number of items to remember and search
43 for)—to test whether or not performance under automatic processing was unaffected
44 by workload. We hypothesized that the mapping of both cues together rather than

the mapping of only one of the cues would affect performance. Specifically, we expected consistent mapping of both cues to result in the best performance. We also expected the consistent mapping of the conjunction of the two cues would result in automatic performance that would be unaffected by workload.

Method

Participants Five participants (one female and four males) with an average age of 22 years participated in this study. Participants were right-handed, had normal color vision, and had corrected or normal acuity. All participants were recruited from local universities and were paid \$11.00 per hour for their participation. Each participant took part in six experimental sessions (each lasting approximately three hours) over six different days for a total of 18 hours of task practice.

Experimental design This experiment was a 2 (color mapping) $\times$ 2 (symbol mapping) $\times$ 2 (memory set size) within-subjects design. Three variables were manipulated in this experiment: (1) the mapping of the color (consistent or varied), (2) the mapping of a symbol (consistent or varied), and (3) the memory set size (1 or 4 items to remember and search for). The conjunction of two cues, type of symbol and color, determined the target set. The symbols used in the experiments were digits (1, 2, 3, 4, 5, 6, 7, and 8) and letters (K, H, D, G, J, L, M, and C). The colors used in the experiment were gold, gray, green, orange, peach, red, yellow, purple, cyan, and blue; these colors were selected from the Visual Basic 6.0 color palette because they are most distinct from each other. It has been shown that the amount of information that can be gleaned through human color perception is maximized at ten colors (Flavell and Heath, 1992).

Figure 5.1 An example of the visual search component of Radar

Each of the eight possible conditions was randomly assigned to a block of 16 frames and each frame had a total of 14 trials (detections). The memory set was shown before each frame. The symbols and colors were either consistently mapped (randomly selected symbols and colors were kept as targets within a frame) or variably mapped (the symbols in a target set could appear as distractors in another target set within a block). A target was defined by a conjunction of color and symbol. The memory-set size was set to either 1 or 4 as it was manipulated in the initial experiments of the dual-process theory of automaticity (Schneider and Shiffrin, 1977). When the memory-set size equaled one, there was only one possible target (defined by the conjunction of a single color and a single symbol). When memory-set size was four, there were four targets (out of 16 possible unique conjunctions of the four colors and four symbols).

The dependent variables were the proportion of correct detections and the average detection time for correct detections.

Results

Proportion of correct detections The 2 (color mapping) × 2 (symbol mapping) × 2 (memory set size) repeated measures analysis of variance on the proportion of correct detections showed significant main effects of color mapping, $F(1, 4) = 7.99, p < .05$, symbol mapping, $F(1, 4) = 44.31, p < .01$, and memory set size, $F(1, 4) = 7.82, p < .05$. The proportion of correct detections was higher under consistent color mapping ($M = .94, SD = .05$) than varied color mapping ($M = .86, SD = .09$); higher under consistent symbol mapping ($M = .96, SD = .05$) than varied symbol mapping ($M = .84, SD = .08$); and higher under memory set size of one ($M = .93, SD = .06$) rather than four ($M = .87, SD = .07$).

The two-way interactions were also significant for color mapping and symbol mapping, $F(1, 4) = 7.99, p < .05$, for color mapping and memory set size, $F(1, 4) = 7.99, p < .05$, and for symbol mapping and memory set size, $F(1, 4) = 7.99, p < .05$. These interactions are shown in Figure 5.2.

Figure 5.2 Two-way interactions for the proportion of correct detections in Experiment 1

Detection time The $2 \times 2 \times 2$ analyses of variance showed significant main effects of color mapping, $F(1, 4) = 35.75, p < .01$, symbol mapping, $F(1, 4) = 16.35, p < .05$, and memory set size, $F(1, 4) = 178.87, p < .001$. The correct detections' responses were faster under consistent color mapping ($M = 756$ ms, $SD = 177$) than varied color mapping ($M = 1030$ ms, $SD = 210$); faster under consistent symbol mapping ($M = 820$ ms, $SD = 155$) than varied symbol mapping ($M = 967$ ms, $SD = 233$); and faster under memory set size of 1 ($M = 756$ ms, $SD = 172$) rather than of 4 ($M = 1031$ ms, $SD = 215$).

The two-way interactions were also significant: color mapping and symbol mapping, $F(1, 4) = 35.75, p < .01$, color mapping and memory set size, $F(1, 4) = 35.75, p < .01$; and symbol mapping and memory set size $F(1, 4) = 35.75, p < .01$ (see Figure 5.3). In detection time, the triple interaction of color mapping, symbol mapping, and memory set size was also significant, $F(1, 4) = 41.67, p < .01$ (see Figure 5.4).

Figure 5.3 Two-way for detection time in Experiment 1

Figure 5.4 Three-way interactions for detection time in Experiment 1

1	Summary	1
2		2
3	The results of Experiment 1 revealed that participants were more accurate and	3
4	faster in detecting targets when each of the cues that defined a target (symbol and	4
5	color) was consistently mapped than when the cues were variably mapped. More	5
6	importantly, the mapping of both cues in conjunction also determined performance.	6
7	Performance was worst when both cues were variably mapped. On the other	7
8	hand, mapping at least one of the cues consistently had a significant benefit on	8
9	performance. Furthermore, when at least one of the two cues was consistently	9
10	mapped, performance was unaffected by workload. In contrast, when at least one	10
11	of the cues was variably mapped, performance was affected by workload. The	11
12	significant three-way interaction on detection time shows that worst performance	12
13	occurred when both cues were variably mapped and individuals worked under	13
14	conditions of high workload.	14
15		15
16		16
17	Experiment 2: Consistency of Responding	17
18		18
19	In this experiment, we manipulated the response mapping by varying the number of	19
20	possible responses (only one or more than one) and the consistency of the responses	20
21	(the same responses or changing responses) throughout practice. The stimulus was	21
22	consistently mapped and defined only by one cue (symbol) throughout practice. We	22
23	also manipulated the time constraint (i.e., the time available for target detection)	23
24	as a factor of workload. We predicted that response mappings would have a	24
25	significant effect on performance despite the consistency of stimulus mapping.	25
26	We also hypothesized frame time would influence performance, specifically in	26
27	cases where response mapping became more complex (when there were many and	27
28	inconsistent types of responses).	28
29		29
30	<i>Method</i>	30
31		31
32	<i>Participants</i> Eight students (two females and six males) with average age of 20	32
33	participated in the study. All participants were right-handed, had normal color vision,	33
34	and had normal or corrected-to-normal visual acuity. All participants were recruited	34
35	from local universities and were paid \$11.00 per hour for their participation. Each	35
36	participant completed six experimental sessions of approximately three hours each	36
37	for a total of 18 hours of task practice.	37
38		38
39	<i>Experimental Design</i>	39
40		40
41	We designed a 4 (response mapping) $\times$ 2 (frame time) within-subjects experiment.	41
42	Two independent variables were manipulated in the experiment: (1) response	42
43	mapping (at 4 levels) and (2) frame time (at 2 levels). Thus, the experiment	43
44	consisted of eight conditions. Each condition was presented twice during the	44

1 experiment. Each condition was presented in a block of 30 frames and each frame 1
2 had 14 trials (detections). A set of targets to remember (memory set) was shown 2
3 before each frame. Thus, a total of 6,720 trials were distributed in six experimental 3
4 sessions. The dependent variables were the proportion of correct detections and 4
5 the average detection time for correct detections. 5
6 6

7 *Response mapping* The four levels of response mapping were defined by 7
8 assigning the four keys corresponding to the four corners of the numeric keypad. 8
9 Thus, four numbers were the possible responses to the target stimulus: 1, 7, 9, and 9
10 3. The keys were color coded with a color sticker on the key (1 = red, 7 = blue, 9 10
11 = green, and 3 = yellow). The participants' goal was to respond by pressing the 11
12 correct key depending on the response mapping condition to which they were 12
13 assigned to: 13
14 14

- 15 1. *Fixed mapping*: participants responded with the same key every time a target 15
16 was detected. All axes on the radar grid were the same color and this color 16
17 determined the correct response key. The color of the axis was randomly 17
18 selected (either red, blue, green, or yellow), shown to the participants, and 18
19 kept constant in each frame. Thus, any time the participant detected a target 19
20 he was to respond by pressing the same key, regardless of where the target 20
21 was detected. 21
- 22 2. *Full mapping*: participants responded with one of the four possible keys 22
23 according to the color of the axes in which the target was detected. For 23
24 example, if the target was detected in the bottom-left corner axis, the correct 24
25 response was to press the 1 key (red). Each of the four axes of the grid were 25
26 color-coded with the same color as the response keys (bottom-left = red, 26
27 top-left = blue, top-right = green, and bottom-right = yellow). 27
- 28 3. *Partial mapping*: participants responded with one of the four possible keys. 28
29 However, in this condition, two of the axes were consistent with the colors 29
30 of the numeric keys and the other two axes were randomly assigned one of 30
31 the four colors. 31
- 32 4. *Random mapping*: participants responded with one of the four possible 32
33 keys, but in this condition, the color of each of the four axes was randomly 33
34 assigned to one of the four colors. Thus, the consistency between spatial 34
35 layout and the color coding of the responses and radar axes was random. 35
36 36

37 *Frame time* The time between the onset of one frame and the next was manipulated 37
38 in two ways: the 'slow' condition was 2,050 ms and the 'fast' condition was 1,050 38
39 ms. For both frame time conditions, the radar grid was presented to the participants 39
40 for 1,000 ms before each trial and the inter-trial interval was 1,500 ms. 40
41 41
42 42
43 43
44 44
45 45

1 Procedure

2
3 Before the onset of each frame, participants were asked to memorize a set of 4
4 targets (either digits or letters). Then they were presented with a sequence of 14
5 trials. Each trial displayed four moving blips. The participant's task was to detect
6 any member of the memory set that appeared in the sequence of trials. Targets
7 could appear in any trial except the first two and last two trials. At the end of each
8 frame, participants received feedback on their performance. In case of an error in
9 detection, a tone sounded at the end of the relevant frame. Participants were also
10 provided with textual feedback at the end of each trial which detailed the type of
11 error made (false alarm, miss, etc.). Stimulus mapping was always consistent and
12 members of the target set never appeared as distractors. For example, when the
13 targets were digits (1–9) the distractors were letters (C, D, F, G, H, J, K, L, and M)
14 and vice versa.

15
16 Results

17
18 Figure 5.5 shows the proportion of correct detections (Panel A) and the detection
19 times (Panel B) averaged by response mapping condition (stimulus, full, partial,
20 random) and frame time condition (slow, fast).

21 The 4 (response mapping) × 2 (frame time) repeated measures analysis of
22 variance revealed main effects of response mapping and frame time only for
23 detection time, and no significant effects on the proportion of correct detections.
24 The interactions between response time and frame time were not significant.

39
40 **Figure 5.5 Proportion of correct detections and detection time in**
41 **Experiment 2**

1 The proportion of correct detections remained relatively stable across mapping 1
2 conditions, particularly in the slow condition. However, although Figure 5.5 2
3 (Panel A) shows a different pattern across response mapping conditions for the 3
4 fast frame times, the interaction between response mapping and frame time was 4
5 not statistically significant. 5

6 On the other hand, detection time of correctly detected targets was clearly 6
7 influenced by both the response mapping $F(3, 21) = 20.31, p < .001$, and the 7
8 frame time $F(1, 21) = 54.95, p < .001$, independently. Detection time increased 8
9 with the difficulty of the response mapping condition. Detections were fastest in 9
10 the mapped-to-stimuli condition ($M = 1056$ ms, $SD = 78.14$) and slowest in the 10
11 random-mapping condition ($M = 1425$ ms, $SD = 61.49$) as expected. Detection 11
12 time was also fastest in the fast condition ($M = 1173$ ms, $SD = 73.97$) and slowest 12
13 in the slow condition ($M = 1391$ ms, $SD = 68.15$). 13

14 14

15 15

16 Summary 16

17 17

18 The results indicated that response mapping significantly affected the detection 18
19 time of correctly detected targets despite consistent stimulus mapping. The results 19
20 however, also indicated that response mapping did not have an effect on the 20
21 proportion of correct detections. Furthermore, time constraints also significantly 21
22 affected detection time, but the effects were constant across response mapping 22
23 conditions. 23

24 24

25 25

26 General Discussion and Conclusions 26

27 27

28 The current studies support the prediction of the dual-process theory in that optimal 28
29 performance after extended practice occurs when targets are consistently mapped, 29
30 rather than variably mapped. However, this research extends the traditional view of 30
31 automaticity by testing the effects of conjunctive search consistency and response 31
32 consistency. 32

33 In the first experiment, we demonstrated the importance of conjunctive 33
34 search consistency. Our results indicated that consistently mapping each of the 34
35 cues that defined the targets, independently, results in better performance. But, 35
36 most importantly, our study indicates that the inconsistency of both cues together 36
37 produced the most detrimental effect on performance. Research on attention 37
38 indicates that a target defined by multiple cues leads to a serial search (Treisman 38
39 and Gelade, 1980). That is, search time can increase with the number of cues and 39
40 the number of levels of cues that are needed to search. Also, research shows that 40
41 cues are processed in serial order (e.g., colors then symbols or symbols then colors; 41
42 Fisher and Tanner, 1992). Thus, previous research suggests that an increased 42
43 number of cues may involve increased serial search. Our results demonstrate that 43
44 if at least one of the cues is consistently mapped, the serial search is faster and 44

45

1 results in more accurate responses, especially when compared with cues that are 1
2 all variably mapped. 2

3 In the second experiment, we demonstrated that response mapping can be 3
4 critical for skill development above and beyond the stimulus consistency. The 4
5 more inconsistent the responses are, the longer it takes to detect targets. This 5
6 extends research that has reported negligible effects of response mapping (Fisk 6
7 and Schneider, 1984; Kramer, Strayer, and Buckley, 1990). Our results revealed 7
8 that, on average, the difference in response times between consistent responding 8
9 (the Fixed response mapping condition) and the Full condition was 184 ms; 9
10 between the Fixed and the Partial condition was 298 ms; and between the Fixed 10
11 and Random mapping condition was 421 ms. These processing costs associated 11
12 with inconsistent responding were considerably higher than in past research by 12
13 Fisk and Schneider (1984), who found a processing cost of 64 ms for inconsistent 13
14 responding and concluded that consistency of responding was less important 14
15 than consistency of attending in the development of automaticity. Also, Kramer 15
16 et al. (1991) concluded that consistency of responding was unnecessary for the 16
17 development of automatic detection and that the processing cost of inconsistent 17
18 responding was small (17 ms). However, as our results demonstrate, when tasks 18
19 are complex and dynamic, the consistency of responding is equally important. 19
20 Therefore, we would expect that in real-world, complex search-and-respond 20
21 tasks, consistency of responding as well as the time constraints in the task can be 21
22 important factors for effective performance. Although our results did not reveal a 22
23 statistically significant interaction between response mapping and time constraint, 23
24 the data suggest that there might be an increasingly detrimental effect of time 24
25 constraints on performance as the inconsistency of responses (or the complexity of 25
26 response mapping) increases. Testing this possibility requires further research. 26

27 27
28 28

29 **Implications for Design and Training** 29 30 30

31 Consistency of mapping was investigated during the visual search and during 31
32 the response. We suggest that performance on a visual search task needs to be 32
33 analyzed on at least these two possible dimensions. As demonstrated by the results 33
34 of these experiments, analyzing a visual search task in terms of the consistency 34
35 of responding and the conjunction of search cues helped identify some important 35
36 impediments in skill acquisition. For example, when the spatial layout of a 36
37 display and the spatial layout of the response keys are redundant (i.e., location 37
38 compatibility), it capitalizes on people's natural tendency to move toward stimuli 38
39 (Simon, 1969; Wickens and Hollands, 2000). When the spatial location of the 39
40 stimulus and the response location are inconsistent (e.g., a target is preset on the 40
41 northwest axis, but the appropriate response is the 9 key or the northeast response 41
42 key), Wickens and Hollands' (2000) collocation and movement compatibility 42
43 principles are violated. However, even when these principles are not violated 43
44 (when the spatial location of the stimulus and the response key are redundant), 44

1 there are still processing costs over inconsistent responding. Thus, when possible, 1
2 system designers should consistently map stimuli and responses to attenuate the 2
3 processing costs associated with response selection. 3

4 Another implication of this research involves a recommendation for training. 4
5 If extensive training is provided with a wide range of stimuli in simulated tasks, it 5
6 is possible to develop automatic detection if at least one of the cues is consistently 6
7 mapped. Individuals can benefit from automatic detection even when they perform 7
8 in the presence of other variably mapped cues. Our future research will be directed 8
9 at exploring the ecological account of the dual-process theory of automaticity in 9
10 all its dimensions, including the effects of spatial and temporal dynamics and the 10
11 multiple forms of consistency of attending and responding. 11

12 12

13 13

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15 15

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20 20

21 21

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