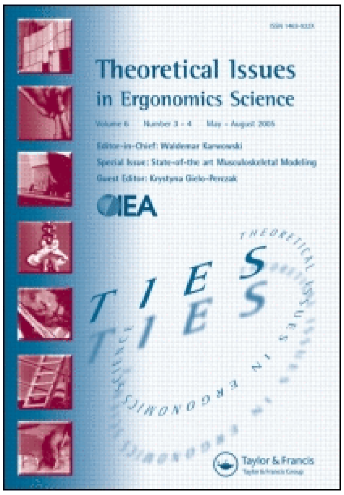

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The relationship between stimulus-response mappings and the detection of novel stimuli in a simulated luggage screening task

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The relationship between stimulus-response mappings and the detection of novel stimuli in a simulated luggage screening task

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Automaticity research suggests that consistent mapping leads to better skill acquisition than varied mapping. Other research demonstrates that in some situations varied mapping leads to better transfer. The effect of stimulus-response mappings in complex visual inspection tasks, wherein transfer stimuli might differ from training stimuli, has seldom been studied. Therefore, the effects of consistency vs variability of practice on learning and transfer in a simulated luggage screening task were compared. Consistent mapping led to faster and more accurate initial skill acquisition. However, during transfer, varied mapping led to higher levels of sensitivities and confidence and fewer deviations from optimal response criteria. Consistent mapping assists initial skill acquisition; however, in tasks where the physical identity of transfer stimuli might differ from those used in training, varied mapping leads to more efficient transfer. The results provide an important starting point for training individuals to achieve optimal transfer of learning in complex tasks. This research demonstrates that a combination of variables influence transfer of learning in real-world visual inspection tasks wherein transfer conditions may not be identical to training conditions. Acquisition of skills during training is facilitated by consistent stimulus-response mappings; however, in order to ensure optimal transfer of skills to situations involving novel stimuli, training should incorporate varied mapping of stimulus-response elements.

Keywords: consistent mapping; varied mapping; stimulus-response mapping; signal detection; transfer of learning; visual search

1. Introduction

The dual-process theory of automaticity (Schneider and Shiffrin 1977, Shiffrin and Schneider 1977) states that performance improvements in visual search tasks are a function of stimulus mapping and task workload: 'automatic processing' develops when targets are consistently mapped through practice; however, under varied-mapping conditions, wherein stimuli may be targets in one instance but distractors in another, performance occurs under controlled processing, which is voluntary, serial and requires attention. Consistent mapping (CM) has been demonstrated to be faster, more accurate and parallel in nature; evidence in support of CM has been found in research covering topics such as ageing and individual differences (Fisk *et al.* 1995, Hertzog *et al.* 1996),

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physical injuries (Schmitter-Edgecombe and Rogers 1997), memory and recognition processes (Glass 1993) and speech monitoring (Mullennix *et al.* 1992).

In contrast to the strong support for CM, many studies on learning have demonstrated that, in some situations, CM does not necessarily lead to better skill acquisition than varied mapping (VM). The earliest support for this are the works of Kristofferson (1975, 1977), who found that after participants were trained under CM conditions, replacement of all the distractors with new distractors (thereby mimicking VM conditions) did not negatively affect automaticity that was developed earlier. Likewise, if all the distractors were held constant and all the targets were replaced, automatic search was still maintained. More recently, Cooke *et al.* (1994) conducted a study wherein they examined the retention of visual search skills for both letter-search and digit-search paradigms, after a period of 9 years of non-use. Digit-search was learned under VM conditions, whereas letter-search was learned under CM conditions. The authors found that for both types of search, there was no loss in visual search skills and minimal loss of speed, regardless of the differences in stimulus-response consistency across the two types of search. This was surmised to be due to the development of automaticity as a consequence of extended practice, with similar long-term retention potential for both CM and VM learning situations.

The research of Strayer and Kramer (1994) extended the above by demonstrating that practising a task when CM and VM trials were mixed diluted the positive effects of CM in visual skill acquisition. Variability of mapping findings indicate that in some special circumstances practising a task under varied conditions can enhance retention and transfer better than practising under consistent conditions. Research by Schmidt and Bjork (1992) has corroborated this by demonstrating that different types of variability during practice, including variability in the way tasks are ordered and in the nature and scheduling of feedback, enhance retention and lead to improved transfer.

1.1. *Purpose of the present study*

In complex visual search tasks such as airline luggage screening, there is a large degree of variability inherent in the task, primarily in the definition of 'targets' and 'distractors'. A 'target' is loosely defined as any object that can be used in a potentially threatening manner and a 'distractor' is defined as any object that does not pose a threat. An example of such variability is security regulations and restrictions that change frequently; objects that are considered distractors on one day may be considered targets on another day (e.g. liquids and gels, nail clippers, small scissors). Not surprisingly, in training-transfer situations, the probability of operators encountering novel targets that they have not been exposed to during training is relatively high. Therefore, it is extremely difficult, if not impossible, to include every potential target in a finite training set. Recent research in luggage screening has revealed that performance improvements during the course of the screening task largely depend on the recognition of familiar targets, i.e. performance improves when transfer stimuli are identical to those used during training (Smith *et al.* 2005b). However, performance degrades when unfamiliar targets from the same categories appear during transfer, thereby demonstrating the inability to use category-general knowledge to extrapolate to unfamiliar objects (Smith *et al.* 2005a, b). Likewise, Healy *et al.* (2006) found that individuals show durability and transfer of performance only when the mental procedures developed during training can be reinstated (i.e. duplicated) at testing. Neither of these studies, however, examined the issue of stimulus-response mapping as a variable during training in the screening task. The primary focus in the present study, therefore, was to examine the probability of harnessing the stimulus mapping variability inherent in the screening task to strengthen transfer to novel stimuli.

Although some research has demonstrated the robustness of training under VM conditions in generic laboratory tasks as described in the earlier paragraphs, it is still unclear to what extent the positive effects of VM-based training generalise to complex cognitive tasks such as luggage screening, wherein performance improvements are not merely a matter of perceptual expertise, but involve a combination of bottom-up processes (changes in the ability to distinguish between signal and noise) as well as top-down processes (changes in the propensity to generate target-present vs target-absent responses). This research attempted to answer this question by examining the costs and benefits of training operators under CM vs VM conditions, when the stimuli encountered during transfer were unfamiliar and had not been encountered previously during training. In contrast to the paradigm used by Kristofferson (1977), both targets (threat objects) as well as distractors (non-threat objects in luggage) were replaced during transfer. This research is based entirely within the signal detection framework and the effects of CM vs VM on changes in sensitivities, shifts in decision criterion settings and subjective confidence were measured. It was hypothesised that training under CM conditions would foster better initial skill acquisition in terms of higher sensitivities, proximity to optimal criterion settings and higher confidence. However, according to the research reviewed above, the opposite was expected during transfer, wherein participants trained under VM conditions would transfer best to novel targets.

2. Method

2.1. *Pre-test*

The purpose of the pre-test was to ensure that the stimuli that would be used to train and transfer learning in the actual luggage-screening experiment were of comparable difficulty. Participants ($n = 10$) were presented with an X-ray image of luggage 40 times in succession on a computer screen. A neutral grey screen appeared between trials to minimise carryover effects. On each of the 40 trials, a new potentially dangerous object was embedded in the luggage image. The participants' task was to click on the target (in the luggage image) as soon as they detected it. 'Traditional weapons' such as guns and knives were excluded and the test focused instead on other unconventional objects that could be used in potentially dangerous ways. An example of an X-ray image of luggage and a subset of the selected targets are presented in Figure 1. Response time (seconds) for detection was measured. In addition, participants rated their perceived difficulty of detecting each object on a scale of 1 (not difficult at all) to 5 (extremely difficult). Both response time and subjective ratings were used as indices of difficulty. Based on both objective response times and subjective difficulty ratings, 20 threat objects were selected, which were most comparable in difficulty for the actual screening experiment described below.

2.2. *The luggage screening simulation*

2.2.1. *Participants*

A total of 33 undergraduate and graduate students completed either the two phases or only the transfer phase of the experiment depending on the group they were randomly assigned to. Specifically, 22 participants (assigned to two experimental groups) completed both training and transfer phases. The remaining 11 participants served as the control

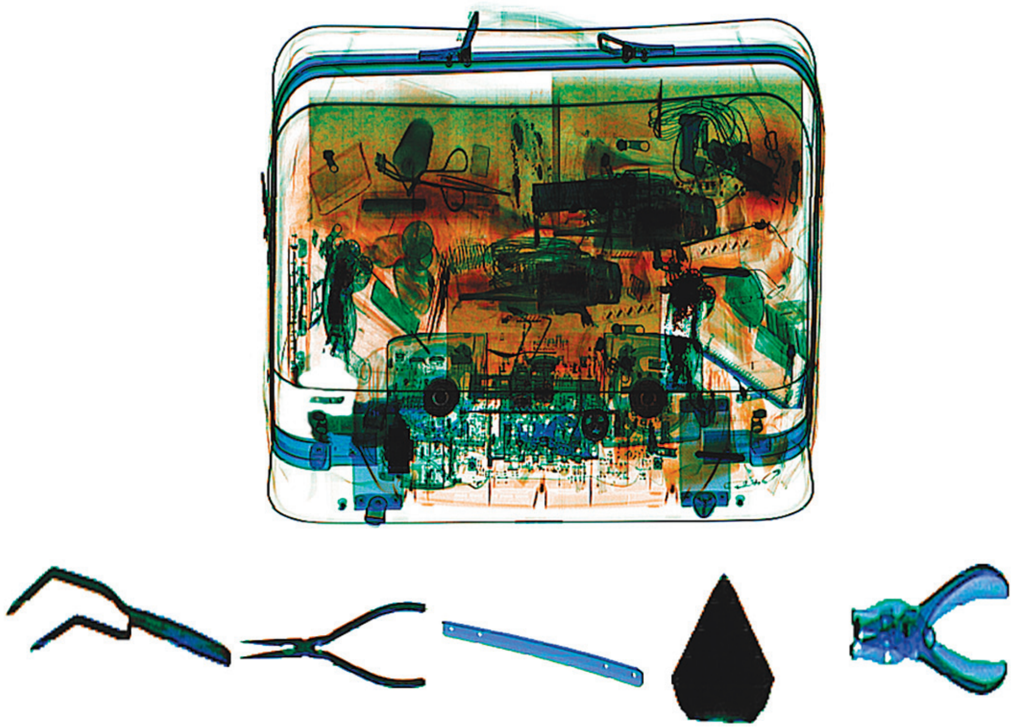

Figure 1. Sample X-ray image and a subset of target stimuli.

group and completed only the transfer phase. All participants were right-handed, had normal colour vision and had normal or corrected-to-normal visual acuity. All participants were paid a total of $20 for their participation. The total participation time did not exceed 2 hours.

2.2.2. *Experimental design*

For the actual experiment, participants were randomly assigned to one of three groups: (1) training under CM conditions ($n = 11$); (2) training under VM conditions ($n = 11$); (3) control (no training) ($n = 11$). Participants in the CM and VM groups completed 600 trials of the luggage screening task in a time span of 2 hours. The 600 images were presented in four blocks of 150 trials. The first three blocks were the training phase, wherein each block was further divided into 15 shifts of 10 trials each and a memory set was presented at the beginning of each shift. The fourth block was the transfer phase with novel targets. In both phases, the target probability (50%) was i.e. 75 bags in every block of 150 bags contained a digitally superimposed target.

2.2.3. *Procedure*

During the three training blocks, participants in the CM and VM groups were asked to memorise a set of five 'threat' objects (randomly drawn from the set of 20 created in the pre-test) at the beginning of each shift. They were then required to detect the presence of these targets in the ensuing luggage images in that shift. In the CM condition ($n = 11$), the five 'threat' objects in the memory set were always targets and never occurred as distractors in any other shift. In the VM condition ($n = 11$), the five targets were drawn from the same set as the targets used in the CM condition. However, objects that appeared as targets in one shift appeared as distractors in other shifts within the same trial block.

After observing the memory set, participants completed a sequence of 10 trials in the shift. At the beginning of each trial, a luggage X-ray image appeared in the centre of the screen for a duration of 4 seconds. Participants were required to search for any member of the memory set that appeared in the luggage image and click on the target when they detected it. If they did not click on the image, the trial timed out after 4 seconds. They then entered their confidence in their decision on a scale of 1 (not confident at all) to 5 (completely confident). This was followed by a text message indicating whether they had generated a hit (probability of correctly detecting a target), miss (probability of failing to detect a target), false alarm (probability of incorrectly identifying a non-target as a target) or correct rejection (probability of correctly identifying a non-target bag).

In the fourth (transfer) block, participants from both CM and VM groups detected 'novel' targets. These objects were also drawn from the original set of 20 targets from the pre-test. However, it was ensured that these targets had never been presented to participants during training and participants were not shown any memory sets at the beginning of the transfer block. Instead, they were instructed to use their knowledge of what the targets could be gained during the acquisition phase to detect the novel targets in this phase. All participants received a 10 min break between the acquisition and transfer phase.

In addition to the CM and VM groups, a third control group ($n = 11$) performed the trial block with novel targets alone without performing the first three training blocks. That is, the control group completed only the 150 trials of the transfer block without any prior practice. The purpose of this condition was to establish a baseline for the difficulty of detecting novel and unfamiliar targets without prior practice. The dependent variables were sensitivity (d'), response criterion setting (c) and decision confidence.

3. Results

Since the stimuli and procedures used in the two phases were different (training phase: same targets + memory set; transfer phase: novel targets + no memory set), the data were analysed separately for each phase using multiple ANOVA. Effect sizes are presented as Cohen's d, with values of 0.8 and greater representing large effect sizes, values between 0.7 and 0.3 representing medium effect sizes and values of 0.2 and lower representing small effect sizes.

3.1. *Sensitivity (d')*

3.1.1. *Training phase*

Results of a 2 (training method: CM vs VM) $\times$ 3 (trial block) mixed ANOVA on sensitivities during training revealed significant main effects for training method, $F(1, 20) = 18.61$, $p = 0.0001$ and trial block, $F(2, 40) = 62.57$, $p = 0.0001$, as well as a significant interaction between training method and block, $F(2, 40) = 8.89$, $p = 0.001$. Figure 2 illustrates that during training, detection sensitivity was significantly higher for individuals who trained under CM conditions than under VM conditions. In general, sensitivities increased across the three training blocks for all participants. However, the

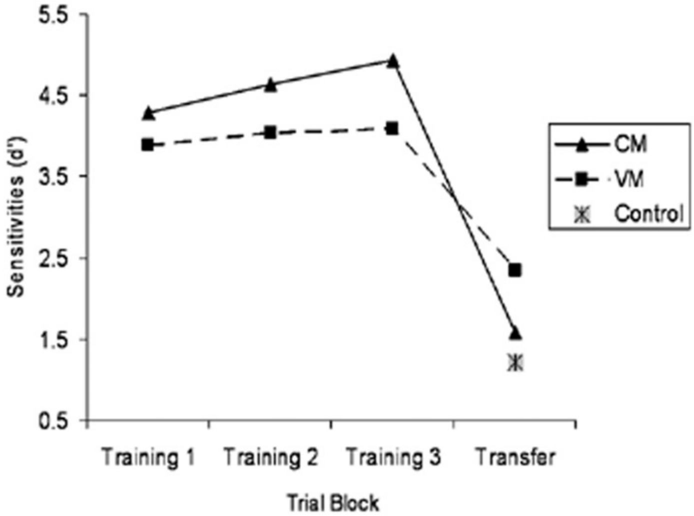

Figure 2. Sensitivities (d') during training and transfer. CM = consistent mapping; VM = varied mapping.

significant interaction between training method and trial block can be explained by the pattern of sensitivities across blocks for CM and VM groups. Figure 2 also shows that sensitivities increased during the course of training for participants training under CM conditions. However, for participants training under VM conditions, sensitivities failed to increase significantly from the first to last block.

3.1.2. *Transfer phase*

Despite the clear advantage of CM over VM during training, there was a reversal during transfer with a significant advantage for participants trained under VM conditions (illustrated in Figure 2, 'transfer block'). As indicated by a one-way ANOVA on sensitivities during transfer, *d*' was significantly higher when individuals were trained under VM than under CM conditions, as well as untrained control participants, $F(2, 33) = 1.92$, $p = 0.051$. However, as can be seen in Figure 2, participants trained under CM conditions did not have significantly higher levels of sensitivities and performed as poorly as control participants during transfer.

3.2. ***Response criterion setting (c)***

3.2.1. *Training phase*

Results of the 2 (training method: CM vs VM) × 3 (trial block) mixed ANOVA on criterion settings revealed a significant main effect for training method, $F(1, 42) = 8.15$, $p = 0.007$, but not for trial block, $F(2, 84) = 0.38$, $p = 0.69$. The interaction between training method and block, $F(2, 84) = 2.25$, $p = 0.11$, did not reach statistical significance. As illustrated in Figure 3, participants who trained under VM conditions were significantly more liberal in their response criterion settings (mean 0.84, SD 0.06) than those trained under CM conditions (mean 1.08, SD 0.06). As a consequence, training under VM conditions increased the potential for false alarms relative to training under CM

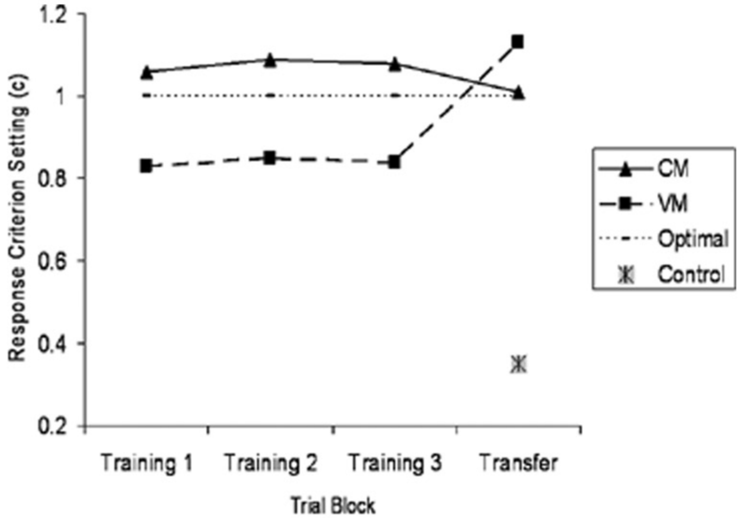

Figure 3. Response criterion settings (c) during training and transfer. CM = consistent mapping; VM = varied mapping.

conditions. Furthermore, as indicated by one-sample t-tests, the criterion settings of participants training under CM conditions did not differ significantly from optimal (mean difference 0.078, $t(21) = 0.99$, $p = 0.33$, $d = 0.43$); on the other hand, the criterion settings of participants training under VM conditions was significantly below optimal (mean difference 0.156, $t(21) = 6.68$, $p = 0.0001$, $d = 2.92$) in the acquisition phase.

3.2.2. *Transfer phase*

The results of a one-way ANOVA on *c* during the transfer phase revealed that both training methods led to criterion settings that were significantly closer to optimal than that of control participants, $F(2, 33) = 14.53$, $p = 0.0001$. However, there were no significant differences between training method alone, $F(1, 43) = 1.22$, $p = 0.275$. This is probably because, as can be seen in Figure 3 ('transfer block'), participants trained under CM conditions and transferring to novel targets demonstrated a significant downward shift in *c*, in the direction of liberal responding from the last training block to transfer, $t(10) = 2.29$, $p = 0.03$, $d = 1.72$. Conversely, participants who trained under VM conditions and transferred to novel targets demonstrated a significant upward shift in *c* from training to transfer, $t(10) = 2.19$, $p = 0.053$, $d = 1.39$.

3.3. *Decision confidence*

3.3.1. *Training phase*

Results of the 2 (training method: CM vs VM) × 3 (trial block) mixed ANOVA on confidence estimates revealed significant main effects for training method, $F(1, 42) = 24.15$, $p = 0.0001$ and trial block, $F(2, 84) = 6.92$, $p = 0.002$, as well as a significant interaction between training method and block, $F(2, 84) = 2.56$, $p = 0.05$. As illustrated in Figure 4, decision confidence was significantly higher for participants who trained under CM conditions than under VM conditions. For participants training under

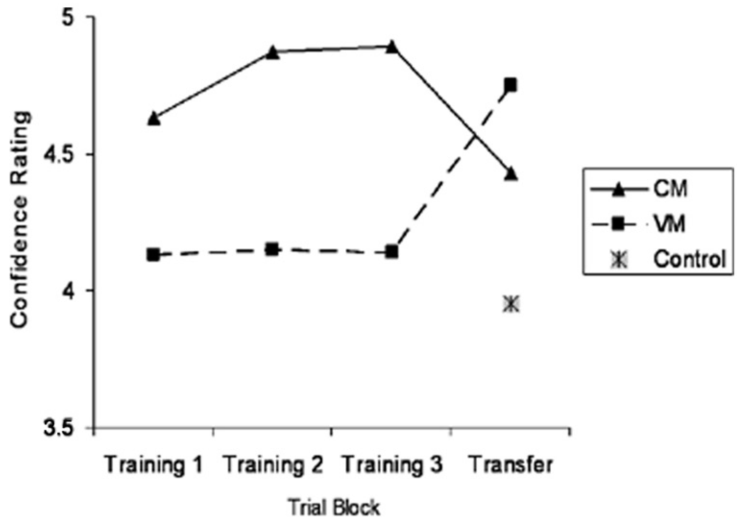

Figure 4. Confidence ratings during training and transfer. CM = consistent mapping; VM = varied mapping.

CM conditions, confidence increased significantly from block 1 to block 3. However, participants training under VM conditions did not demonstrate any statistically significant changes in confidence during the course of training.

3.3.2. *Transfer phase*

Similar to the results for criterion settings, all participants who received prior training (CM and VM) were significantly more confident during transfer than the control group, $F(2, 33) = 4.63$, $p = 0.021$. This is illustrated in Figure 4 ('transfer block'). Moreover, decision confidence during transfer was significantly higher when individuals were trained under VM than under CM conditions, $F(1, 43) = 4.72$, $p = 0.036$. This is primarily because of a significant reduction in confidence from the acquisition block to the transfer block for participants who were trained on CM conditions. The opposite was true for participants trained on VM conditions. These participants exhibited a significant increase in confidence from the acquisition block to the transfer block, $t(10) = 2.75$, $p = 0.02$, $d = 1.74$.

4. Discussion

This research examined detection accuracy and confidence in a complex visual inspection task from the perspective of the dual-process theory of automaticity. Specifically, the study examined the hypothesis that variability of stimuli during training rather than consistency positively impacts transfer of learning when the conditions of transfer differ from training conditions. The research was based entirely within the signal detection paradigm and the effects of VM during training on sensitivity increments/decrements, shifts in response criterion settings and decision confidence were examined. The crux of this research is the effectiveness of CM vs VM training under novel conditions of transfer.

The results of the study indicate that training over a span of 450 trials did help transfer to unfamiliar novel targets (as evidenced by sensitivity levels) but only when training occurred under VM conditions. Confidence, on the other hand, was higher for all trained participants relative to untrained control participants. In keeping with past research, training on CM paradigms provided an initial learning advantage relative to VM paradigms during the acquisition phase in terms of higher levels of sensitivity, proximity to optimal criterion setting and higher levels of decision confidence. When transfer conditions differed from training conditions, as is characteristic of several real-world tasks, overall performance accuracy (in terms of sensitivities and criterion settings) dropped for all participants (in many cases transfer performance was even worse than at the start of training). This suggests perhaps that owing to the complexity of the task more extensive practice was required for all participants in order to minimise performance decrements at transfer. However, when comparing CM and VM groups at transfer, results revealed that training under CM conditions was more debilitating than VM for transfer performance. Specifically, training on CM and transferring to novel stimuli resulted in a larger reduction in sensitivities. In fact, participants trained on CM conditions demonstrated levels of transfer sensitivities that were as low as untrained control participants. This supports the hypotheses that the probability of accurate transfer was higher when participants were trained under VM conditions than on CM conditions.

Interestingly, the drop in sensitivity was accompanied by proportionate decrements in decision confidence during transfer only for the CM group. The opposite was true for participants training under VM conditions, who demonstrated an increase in confidence when transferring to novel targets. It is important to note that this inflated confidence for the VM group was not justified by proportionately high detection sensitivities at transfer, thereby suggesting a pattern of overconfidence. The VM group was exposed to a wider variety of targets during training. It is possible that this larger 'repertoire of potential targets' in memory led to higher assessments of their own ability to perform the task at transfer.

The pattern of results for criterion settings suggests a different trend. When transferring from VM to novel conditions, analyses revealed a significant upward shift in c away from optimal. On the one hand, this upward shift benefited transfer by reducing the incidence of false alarms that was characteristic of participants being trained under VM conditions. On the other hand, this shift also potentially hurt performance by reducing the hit rate. Though reductions in hit rate were compensated for by increases in sensitivity levels, the pattern for criterion settings raises the question of whether improvements in sensitivity and increases in confidence led to unprecedented levels of conservative responding, again presenting the notion of overconfident responding for VM participants. This, however, is a conjecture, since the data do not provide a sufficient basis to establish a causal relationship between sensitivity, criterion settings and confidence in the present study.

Although the reduction of false alarms is perhaps not as critical as the reduction of misses in the context of luggage screening, false alarms do lead to significant losses of time and energy and create additional inconveniences to passengers and security personnel. These inconveniences induced by false alarms would likely lead operators to intentionally ignore potential threats in the future, a phenomenon known as the 'cry wolf effect' (Breznitz 1983), which is a common problem in vigilance paradigms. Therefore, the reduction of false alarms was an important and significant positive effect of VM in the present study.

4.1. *Transfer of learning to novel conditions*

The results of this study support observations that the variability of stimulus-response associations during practice produces the most effective generalisation of knowledge to novel transfer conditions. This result can be explained through the processes described in theories of similarity and decision making. Research suggests that the effectiveness of future decisions is directly determined by the similarity between memory traces of past decisions (instances) and the current decision situation (Gonzalez *et al.* 2003). Presenting one set of objects consistently as targets (in the CM condition) likely increased the memory representation of those objects as targets, thereby making it more difficult to generalise the knowledge to objects that were different from the original targets. However, when objects were used interchangeably as targets and distractors on VM trials, the objects likely became more 'flexibly represented' in memory. Presenting the same object as a target or distractor likely increased the 'subjective preparedness' to perceive physically different targets during transfer. This subjective preparedness potentially led to improvements in the ability to distinguish between signal and noise, a consequent increase in decision confidence and a shift in response criteria toward conservative responding.

Consistent with findings on simple perceptual tasks (Schneider and Shiffrin 1977, Shiffrin and Schneider 1977), the results of the present study indicate that initial skill acquisition is faster when the stimulus mapping is consistent, presumably due to the triggering of an automatic consistency-based retrieval process. However, to the contrary, this research also suggests that training under high levels of mapping variability leads to a more efficient comprehension of task requirements. Mirroring the early work of Kristofferson (1977), the replacement of training targets by novel targets in the transfer phase maintained automatic detection under VM training conditions. However, there were two key differences in the current study. The first difference is methodological – 100 unique luggage images were used in each trial block; therefore, the distractors in the present study were not exactly the same during transfer as in Kristofferson's paradigm; essentially, in this task both targets and distractors were changed.

The second, and perhaps more important difference, is that the performance maintenance upon target replacement observed by Kristofferson held true only for participants trained under VM conditions but not CM conditions in the current study. Transfer of learning for participants trained under CM conditions was significantly poorer when training targets were replaced with novel targets. It is possible that VM during training exposed participants to a wider range of training exemplars and presumably led participants to evolve a more sophisticated recognition process based on their understanding of the relational properties of the exemplars used in training. This suggests the development of an analogical encoding process that led to a transition from a decision strategy based on a limited set of stimulus features to a strategy based on a deeper understanding of the properties of potential targets. These findings are supported by the work of Cooke *et al.* (1994), wherein better retention and transfer of knowledge resulted when skills were acquired through VM training, although the task in this study demonstrated a much more rapid learning and transfer process than Cooke *et al.*'s (1994) 9 year paradigm.

An alternative explanation for the observed improved transfer for VM training conditions relates to a recent experiment by Cousineau and Larochelle (2004). They examined the effects of a 'categorical VM' condition, in which different sets of stimuli switched roles as targets and distractors over trials. The stimuli used in these various mapping conditions were digits, letters or a combination of digits and letters. Analyses of the response time means obtained early and late in training indicated that the presence of categorical distinctions among the stimuli was the most important determinant of search efficiency. The authors used a feature-based comparison model to account for the improvements in performance obtained after extensive training. According to the model, improvement in search efficiency resulted from a reduction in the number of features considered. In this study, although the pool of targets was the same for both CM and VM conditions, the VM condition was structured such that categorical differences (if any) between targets and non-targets were likely more salient during training. This category-based approach potentially made it easier for participants to differentiate between targets and distractors. This explanation, however, is conjecture since this study did not create special categorical differences among stimuli. All targets were drawn from the same pool of objects that were equally difficult to detect.

4.2. *Conclusions and implications*

There are some limitations in the design of this study, which affect the generalisability of the results to actual luggage screening contexts. The study used a relatively contrived situation where the participants were college students. Consequences of wrong decisions (i.e. negative feedback) do not compare to those faced when a threatening object is undetected by security systems at an actual airport. Furthermore, the duration of the task (less than 2 hours) was shorter than the shifts typical in a real airport and the base rate of targets in this study (50% for statistical purposes) was significantly higher than the base rate in the real world. These factors could potentially have influenced participants' response patterns, particularly their criterion setting and levels of confidence.

Despite these limitations, however, the results of the present study suggest that methods of training that consistently map targets will likely lead to better initial acquisition of skills than VM of targets but not necessarily better transfer. This research draws attention to the trade-off between training for optimal training and the potential for maximal transfer when conditions of transfer differ from the conditions of training in a multitude of ways. Therefore, training programmes must focus not only on the effectiveness of initial learning, but also on the durability and transferability of the knowledge acquired when the training variables are modified. Many layers of security must be upgraded to achieve a system that is as secure as it is safe (Hancock and Hart 2002). Therefore, further research is required before the suggestions drawn from laboratory experiments can be generalised to develop actual training modules for security personnel. The present research, nevertheless, provides a valuable starting point.

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