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Preschoolers out of adults: Discriminative learning with a cognitive load

Sylvain Sirois
University of Manchester, Manchester, UK

Thomas R. Shultz
McGill University, Montreal, Quebec, Canada

This paper explores novel predictions from the spontaneous overtraining interpretation of human discrimination shift learning (Sirois & Shultz, 1998a). Results from six experiments where adults perform a discrimination shift task with or without a cognitive distractor are reported. In three experiments with a concurrent distractor task (Experiments 1A, 2A, and 3A), performance of adults is comparable to what would be expected from preschoolers performing only the learning task. These adults show no dimensional transfer from initial learning, unless new attributes are introduced in shift learning. On the same tasks without a cognitive load (Experiments 1B, 2B, and 3B), performance is typical of normal adults. The discussion focuses on the relative ability of competing theoretical models (i.e., *levels of processing*, *attentional mediation*, and *perceptual differentiation*) to account for these data.

The ability to categorize information is an important, basic skill for most cognitive activity. Of the various paradigms developed to investigate category formation, concept shift tasks focus on simple forms of categorization (Wolff, 1967). In such tasks, participants learn to classify stimuli in various categories, based on stimulus features such as shape, size, and colour (or their combinations; e.g., Kruschke, 1996). Categories can also be arbitrary, whereby complex objects form haphazard categories (Bogartz, 1965; Goulet & Williams, 1970). When a success criterion is attained, a shift in reward contingencies is introduced such that learners must acquire new categories. Performance in the relearning phase is assumed to reflect category formation, as previous categories must be ignored and new categories acquired. By careful manipulation of category properties, researchers can identify the principles of category learning.

Discrimination shift tasks are an elementary subset of concept shift tasks and have led to a

Correspondence should be addressed to Sylvain Sirois, School of Psychological Sciences, The University of Manchester, Oxford Road, Manchester, M13 9PL, UK. Email: sylvain.sirois@man.ac.uk

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substantial body of empirical and theoretical work (Esposito, 1975; Wolff, 1967). The origins of this line of research can be traced to Lashley's (1929) early work on animal learning and later methodological progress from Spence and his colleagues (e.g., Spence, 1952, 1956; Spence, Goodrich, & Ross, 1959). Research by Howard and Tracy Kendler, beginning in the late fifties, was instrumental in generating an important body of research in human discrimination shift learning, focusing especially on developmental issues (see Esposito, 1975, and Wolff, 1967, for extensive reviews; see H. H. Kendler, 2002, for a detailed chronology).

Despite decades of research and a large body of robust and replicable data, an integrated theoretical interpretation failed to emerge. We have recently proposed a novel interpretation of human shift performance, which we called the *spontaneous-overtraining* hypothesis (Sirois & Shultz, 1998a, 1998b). We hypothesize that children above the age of 10 and adults, as opposed to preschoolers, engage in extensive covert processing during discrete trials of a discrimination shift task, enabling them to form focused representations of the target categories, which in turn affect shift-learning performance. We tested this novel interpretation in artificial neural network models, and the results of the simulations provide unprecedented coverage of discrimination shift data (Sirois & Shultz, 1998b).

The purpose of the current paper is to devise an empirical test of the core assumption of the spontaneous-overtraining hypothesis. Specifically, we predict that we can produce in adults a pattern of performance similar to that observed in preschoolers by blocking spontaneous overtraining in discrimination shift tasks.

Discrimination shifts: Basic tasks and data

In basic discrimination shift tasks, learners are presented with pairs of stimuli having mutually exclusive attributes on three binary dimensions (e.g., shape, colour, and position). Figure 1 shows four possible pairs of stimuli that exhaust the mutually exclusive combination of shape (square and circle), colour (black and white), and position (left and right).

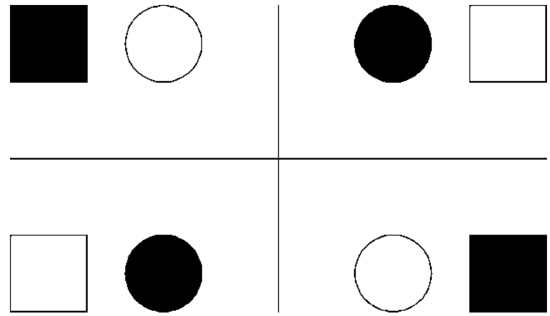

Figure 1. *Four stimulus pairs that exhaust the mutually exclusive combination of shape, colour, and position.*

In the preshift learning phase, learners are required to respond consistently to one attribute from one dimension (e.g., *square*). That is, shown any of the four stimulus pairs, they must choose the stimulus with the target attribute. Learning is guided by feedback or reward over repeated presentations of all stimulus pairs, and it continues until the target attribute is reliably selected (typically, on 8 out of 10 consecutive trials). When the success criterion is achieved, a variety of shifts in reward contingencies may be presented.

In a reversal shift (RS), the remaining attribute of the initially relevant dimension becomes the target (e.g., a shift from *square* to *circle*). Learners performing a reversal shift must change their initial responses for all pairs in the shift-learning phase. A reversal shift is shown in the first row of Figure 2.

With a nonreversal shift (NS), an attribute from a previously irrelevant dimension is selected as the new target (e.g., shifting from *square* to *black*). During the shift-learning phase, responses must be changed for only half of the stimulus pairs (e.g., no change is required for the one half of the squares that are black). An example is shown in the second row of Figure 2.

RS and NS can be referred to as "continuous tasks", because the same stimulus attributes are used during both learning phases. Two other basic shift-learning tasks are referred to as "total

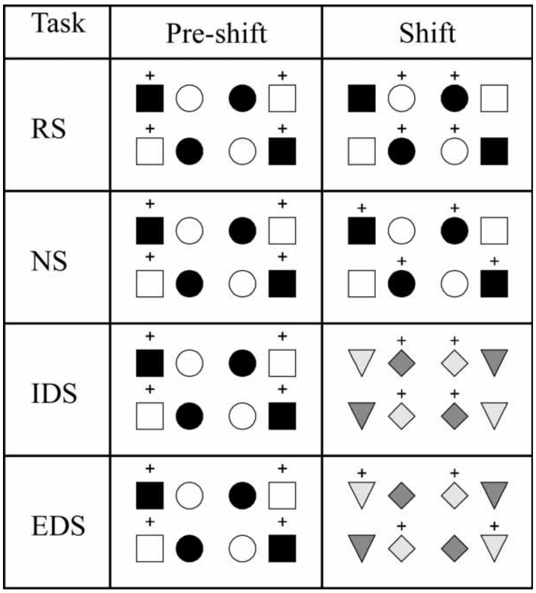

Figure 2. *Examples of reversal (RS), nonreversal (NS), intradimensional (IDS), and extradimensional (EDS) shifts. In each phase of each task, four possible pairs of stimuli are shown. Plus signs identify which stimulus in a pair is rewarded. In all examples, initial training is with square as the target.*

change" tasks (Esposito, 1975), where novel attributes are introduced at the onset of shift learning. An intradimensional shift (IDS, third row of Figure 2) is similar to a reversal shift, in that the new target is from the initially relevant dimension (e.g., from *square* to *diamond*). An extradimensional shift (EDS, fourth row of Figure 2), conversely, is similar to a nonreversal shift, as the new target is from an initially irrelevant dimension (e.g., from *square* to *light grey*).

The optional shift (OS), which can be used in continuous or total change conditions, has been used more often as a continuous task. Figure 3 shows the three phases of an optional shift task. In the initial learning phase (Figure 3, left), participants learn a discrimination task with four pairs of stimuli. When criterion is reached, the shift-learning phase begins, using only two of the original four pairs (Figure 3, centre). These pairs are selected such that the shift is consistent with both a reversal and a nonreversal shift. That is, from only these two pairs, the shift could be within the original dimension (i.e., *square* to *circle*) or between dimensions (i.e., from *square* to *black*). The key question in this task is whether participants generalize the shift to the two remaining stimulus pairs. During the test phase (Figure 3, right), the shifted reward contingencies are maintained for the pairs used in the shift-learning phase, but for the two test pairs not used in the shift phase, either stimulus is rewarded. Participants who consistently pick the test stimuli consistent with a reversal shift (i.e., they have changed their original response) are labelled *reversers. Nonreversers* are those participants who are not labelled reversers (i.e., they do not reliably shift their initial response to the test pairs).[1]

Adults and children above the age of 10 years usually perform RSs faster than NSs (Esposito, 1975; H. H. Kendler & Kendler, 1975; T. S. Kendler, 1983, 1995; T. J. Tighe & Tighe, 1978; Wolff, 1967). A similar effect is observed with total change tasks, as IDSs require fewer relearning trials than do EDSs (Esposito, 1975; Wolff, 1967; Zeaman & House, 1963, 1974). Finally, the vast majority of adults exhibit reversal behaviour on the OS task; shift learning generalizes to the test pairs. The overall pattern of performance suggests positive transfer from initial learning to shift learning. Shifts within the initial dimension are faster and generalize to test items.

A somewhat different picture emerges from the performance of preschoolers. Whereas positive transfer takes place in total change tasks (i.e., IDSs are learned quicker than EDSs), RSs and NSs are learned equally quickly (Esposito, 1975; Sirois & Shultz, 1998a; Wolff, 1967). This contradicts a pervasive assumption in the discrimination shift literature: namely that preschoolers perform an NS quicker than an RS

[1] This asymmetry in categorizing performance into reversers or nonreversers is a legacy of how these tasks were used (e.g., T. S. Kendler, 1983). Our benchmark analyses in Experiment 3 will rely, by necessity, on a definition of nonreversers as participants not classified as reversers.

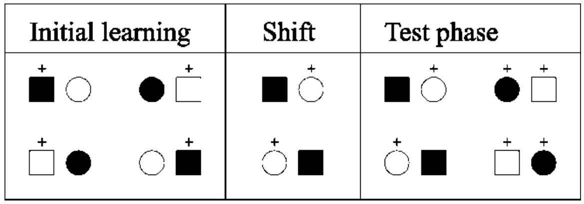

Figure 3. *Example of the optional shift task (OS): initial learning (left); shift learning (centre); test phase (right).*

(e.g., T. S. Kendler, 1983; Raijmakers, van Koten, & Molenaar, 1996). We have suggested that the original studies reporting nonreversal superiority in preschoolers (i.e., T. S. Kendler & Kendler, 1959; T. S. Kendler, Kendler, & Wells, 1960) involved methodological confounds that prevent a valid comparison of RS and NS performance, either by pairing the stimuli based on the originally relevant dimension or by introducing new attributes that held the initially relevant dimension constant (Sirois & Shultz, 1998a). Moreover, the bulk of the literature suggests that there is no overall performance difference for RS and NS in preschoolers (Esposito, 1975; Wolff, 1967). As for the OS task, most preschoolers do not show consistent transfer from the shift-learning phase to the test items and are labelled *nonreversers.*

The overtraining effect (T. S. Kendler, 1983; Wolff, 1967) is worth special consideration before we end this section. This is observed when additional training trials (usually 20 or more) are given in the preshift learning phase, after criterion is reached. Whereas this has little effect on the performance of older children and adults,[2] preschoolers provided with extensive training execute a reversal shift faster than a nonreversal shift (Wolff, 1967). In optional shift tasks, overtraining after the initial learning phase increases the proportion of *reversers* in preschoolers (Eimas, 1967; Shepp & Adams, 1973; T. J. Tighe & Tighe, 1966b). Overall, then, overtraining transforms the pattern of performance of preschoolers on discrimination shift tasks such that it mirrors the performance of older children and adults.

Theoretical interpretations

Three influential interpretations of human shift learning were formulated over the years. These are: (a) the levels-of-processing interpretation (H. H. Kendler & Kendler, 1962, 1969, 1975; T. S. Kendler, 1979, 1983), (b) the attentional mediation interpretation (Zeaman & House, 1963, 1974, 1984), and (c) the perceptual differentiation interpretation (L. S. Tighe & Tighe, 1966a; T. J. Tighe & Tighe, 1966b, 1972, 1978).

According to the levels-of-processing interpretation of the Kendlers (H. H. Kendler & Kendler, 1962), preschoolers learn a discrimination task by forming simple associations between stimuli and responses, based on compound properties of the stimuli used (i.e., responding positively to the black square and to the white square as wholes when the training target is *square*). As children grow older, however, developmental changes allow them to use intermediate categories in order to mediate the processing of stimuli into responses (this was a neobehaviourist interpretation). The categories, it is argued, represent the discrete attributes involved in the task (e.g., *square, black*, and so on). This interpretation can account for performance on continuous discrimination shift tasks, albeit with an important limitation: It wrongly predicts that preschoolers will execute a nonreversal shift quicker than a

[2] It is noteworthy that on a more difficult discrimination shift problem with integers, college-age students benefited from overtraining and learned a reversal shift quicker than did students only trained to criterion (Szalai, 1985).

reversal shift. Furthermore, it fails to explain performance in total change tasks. For adults and older children, categories used in the preshift phase would be of little use in the shift-learning phase when new attributes are introduced. No transfer in total change tasks should take place for preschoolers either, given the purported nature of initial associations.

Zeaman and House (1974, 1984) suggested that the intermediate response between stimulus and overt response is attentional rather than categorical, in contrast with the Kendlers. According to their attentional mediation interpretation, when participants reach criterion in the preshift phase, they have learned both to attend to the appropriate dimension (e.g., *shape*) and to make the appropriate response within that dimension (e.g., *square*). This interpretation suggests that preschoolers also use such dual-level attentional processes, explaining the common ease of IDS over EDS. The important limitation of this hypothesis is that it fails to account for the various preschooler data in continuous discrimination shift tasks by predicting dimensional transfer (Sirois & Shultz, 1998a).

The Kendlers' (H. H. Kendler & Kendler, 1962) and Zeaman and House's (Zeaman & House, 1974, 1984) models were developed mainly with the use of continuous and total change tasks, respectively. T. J. Tighe and Tighe (1978) argued that these tasks stress different processes, and thus the mediational accounts should be viewed as complementary. Despite this possible harmony between the two mediational accounts, Tighe and Tighe developed their own interpretation based on perceptual differentiation theory (J. J. Gibson & Gibson, 1955). According to perceptual differentiation, discriminative learning involves identifying invariants consistent with reward in a sequence of stimuli (L. S. Tighe & Tighe, 1966a). Through experience, it is argued, adults would have acquired well-defined differentiated associations to the relevant and irrelevant dimensions, allowing them to focus on relevant information. This would account for the ease of shifts within the initially relevant dimension, whether or not novel attributes are introduced at the onset of shift learning. Conversely, it is argued that poor differentiation in preschoolers, due to a lack of extensive prior experience, would account for their performance in the continuous tasks. That is, changing half of their learned responses in a NS would be easier than changing all learned responses in a RS, given their inability to appropriately distinguish relevant and irrelevant dimensions. In total change tasks, however, novel attributes make learned responses obsolete, and minimal dimensional differentiation acquired in the preshift phase would allow shifts within this dimension (i.e., IDS) to be learned quicker.

Despite failing to account for the lack of difference between reversal and nonreversal shifts in preschoolers, the perceptual differentiation interpretation provides a natural explanation for the overtraining effect. The qualitative change from preschooler to adult performance in preschoolers is viewed as a function of additional experience.

We have proposed an alternative interpretation of human shift learning that we have called spontaneous overtraining (Sirois & Shultz, 1998a, 1998b). The overtraining literature suggested that the performance of preschoolers can emulate that of adults by means of additional training trials. We thus hypothesized that older individuals are spontaneously providing themselves with more training during discriminative learning, and this is achieved through iterative covert processing.

We assume that the amount of iterative overt processing increases with age between the ages of 4 and 10 years, consistent with developmental work on memory (Flavell, Beach, & Chinsky, 1966; Hagen, Jongeward, & Kail, 1979) and learning tasks that tap short-term memory resources (Case, Kurland, & Goldberg, 1982; Inglis, Ankus, & Sykes, 1968). Within the discriminative learning literature, the idea is supported by earlier work by Levine (1966, 1975) on his hypothesis-testing theory. Subsequent research by Kellogg, Robbins, and Bourne (1978), criticizing Levine's hypothesis-testing theory, provides additional support for spontaneous rehearsal (Sirois & Shultz, 1998a).

Explaining age-related changes in shift-learning performance as a function of spontaneous overtraining allows us to remove a long-standing puzzle in the literature. The levels-of-processing account of the Kendlers, which was the most influential of the three accounts reviewed earlier, suggested that the different pattern of performance of preschoolers and older children reflected a developmental transition from associative learning to mediated learning. Attentional mediation and perceptual differentiation, however, appealed to increased experience and not development. However, it appears at best puzzling that overtraining could circumvent developmental or experiential changes that otherwise unfold over several years. Spontaneous overtraining in adults explains age-related differences in terms of degree rather than kind, which integrates overtraining findings seamlessly with the rest of the shift-learning literature.

If the change from preschooler to adult performance is a function of spontaneous overtraining, it follows that we could produce preschooler performance in adult participants by blocking spontaneous overtraining. This is the opposite of overtraining research, which produces adult performance in preschoolers. In the next sections, we report six experiments testing this prediction. Experiments 1A and 1B examine RS and NS by blocking rehearsal or not, respectively. Experiments 2A and 2B examine IDS and EDS in a similar fashion, while Experiments 3A and 3B consider optional shift learning. B experiments are essentially nonblocking controls for A experiments.

EXPERIMENTS 1 AND 2: SHIFT LEARNING WITH A COGNITIVE LOAD

In these experiments, we examine the shift-learning performance of adults as a function of whether or not they were required to simultaneously perform a counting task. Our hypothesis is that the counting task, serving as a cognitive load, would prevent the extensive covert processing that adult participants would normally use in a discrimination shift task. We thus expect their performance to be similar to that of preschoolers; namely, RS and NS should require a comparable number of learning trials (Experiment 1A), while IDS should be quicker than EDS (Experiment 2A). If the distractor does not unduly affect participants' performance, however, they should also perform the RS quicker than the NS. Finally, in the absence of a distractor (Experiments 1B and 2B), shifts within the initial dimension (RS, IDS) should be quicker than comparable shifts between dimensions (NS and EDS, respectively). Experiments 1B and 2B are used to assess that the shift-learning procedures in corresponding experiments produce the expected pattern of results in the absence of the distractor task. Although these experiments were conducted separately, they are jointly reported in this section so that we can combine data for some of the analyses.

We used the Brown–Peterson task (Brown, 1958; L. R. Peterson & Peterson, 1959) as a cognitive load. This task has been expressly developed to block rehearsal (Benjafield, 1997; Glass & Holyoak, 1986; Payne & Wenger, 1998; Tsiakas, Gagnon, Awad, & Messier, 2004). The task requires that participants count backwards by steps of 3 from a large number. In most cases, however, such as in ours, the experiment ends when the task from which participants are distracted is completed or when a prespecified distraction duration has come to an end.

Although the relevant shift-learning literature predates the routine reporting of effect sizes (and sometimes even standard deviations), it can be estimated from a range of sources (e.g., Cole, 1973; Wolff, 1967) that the effect size of the difference in mean shift trials to criterion approaches 1 in children. If we plan from a large yet conservative effect size d of 0.85, with alpha at .05, a sample of 50 participants for distracted experiments (1A and 2A) would give our statistical tests a power of 0.83. For control experiments, an effect size of 1 and a sample of 30 participants would yield the same statistical power of .83. In our analyses of group differences, we use Cohen's *d* as a measure of effect size (Cohen, 1988) and use pooled standard deviations as the standardizing terms (Rosnow & Rosenthal, 1996).

Method

Participants

Experiment 1A. The 50 participants in this experiment were psychology undergraduates at McGill University. They took part in the experiment in exchange for course credit or for possible monetary reward (through a lottery). Over the course of data collection, 16 participants were replaced (4 counted improperly, 6 paused their counting to focus on the discriminative learning task for 2 or more trials, 4 reached the maximum number of trials in the preshift phase, and 2 completed the cognitive load before completing the shift-learning task). The final sample consists of 39 females and 11 males. Mean age of participants was 20.08 years ($SD = 1.43$).

Experiment 1B. The 30 participants in this experiment were psychology undergraduates at McGill University. They took part in the experiment in exchange for possible monetary reward (through a lottery). Over the course of data collection, 1 participant was replaced (for reaching the maximum number of trials in the shift-learning phase). The final sample consisted of 20 females and 10 males. Mean age of participants was 20.67 years ($SD = 2.44$).

Experiment 2A. The 50 participants in this experiment were undergraduates at McGill University. They took part in the experiment in exchange for possible monetary reward (through a lottery). Over the course of data collection, 11 participants were replaced (10 paused their counting to focus on the discriminative learning task for two or more trials, and 1 reached the maximum number of trials in the preshift phase). The final sample consisted of 39 females and 11 males. Mean age of participants was 21.9 years ($SD = 3.25$).

Experiment 2B. The 30 participants in this experiment were psychology undergraduates; 20 were from McGill University, and 10 were from Birkbeck College, University of London. They took part in the experiment in exchange for possible monetary reward (through a lottery). The sample consisted of 20 females and 10 males. Mean age of participants was 20.67 years ($SD = 2.44$).

Apparatus

The discrimination shift task was presented on a computer, with the screen set at a resolution of 640 by 480 pixels, and with black as the background colour. The stimuli used for the continuous discrimination shift tasks (Experiments 1A and 1B) varied on shape (circle or square), colour (blue or green), and position (left or right). The diameter of the circles, equal to the width of the squares, was 150 pixels. Green was set as RGB (0 255 0), and blue as RGB (0 0 255). In total change tasks (Experiments 2A and 2B), new shapes and colours were introduced at the onset of shift learning. The shapes were an eight-pointed star and a hexagon, both 150 pixels wide. New colours were red, set as RGB (255 0 0), and grey as RGB (132 132 132). On each trial, a pair of stimuli was presented on the centre of the screen with a horizontal distance of 130 pixels between stimuli. Position was not used as a possible target dimension.

The computer was used to present instructions to participants, to randomly select whether individual participants would perform a shift within or between dimensions (with the constraint that there should be an equal number for each type in each experiment), and to administer the shift-learning task. A response box was used to record participants' responses on the shift-learning task.

Procedure

Participants took a seat in front of a desk on which the computer and the response box were set. The distance between the screen and the participant's eyes was about 60 cm. After entering their age and gender on the computer, participants in Experiments 1A and 2A were informed that they would be performing two tasks simultaneously. One task would require interacting with the computer, and the other task involved performing subtractions verbally.

Information about the computer task was then presented. Participants were instructed that pairs of stimuli would be repeatedly presented on the screen and that these stimuli were classified according to one property. The task would be to learn which property was the target. On a given trial, participants were instructed to select either the left or the right stimulus by pressing the corresponding button on the response box. They would then receive feedback about their choice (i.e., whether they were correct or wrong). Participants were instructed that only one stimulus in a pair would bear the target attribute and that furthermore the target could change in the course of the experiment. Participants in Experiment 2A were also told that attributes could change during the experiment. All participants were asked to perform as well as they could. They were told that most people do very well (in order to induce an incentive to perform well on the shift-learning task).

The counting task was then presented. Participants were told that a starting number would be displayed on the screen and that their task would be to start counting backwards by steps of 3 from that number. An example was given: "For example, if the number displayed is 127, you would go: '127, 124, 121, 118, 115'." Participants were instructed to count as fast and as well as they could and that they should continue counting despite making errors. They were instructed to do as well as they could on the computer task, but not at the expense of the counting task. Participants were told that the experiment would end when they reached 0 on the counting task. They were asked to count aloud, as the computer would be recording their counting. This was intended to induce an incentive to perform well on the counting task: The computer did not record audio in this experiment.

When the experiment started, the computer instructed participants to start counting backwards from 687. This instruction remained on the screen for 15 s in order to provide participants with some experience on the counting task before the shift-learning task started. The experimenter informed participants that they should start counting if they failed to start after a few seconds. A period of 15 s after the starting number had been displayed, the screen was cleared, and the first stimulus pair was displayed. The preshift phase of the shift-learning task started.

On a given trial, the computer randomly selected without replacement one of the four possible stimulus pairs and displayed the corresponding image. The pair remained on the screen until the participant pressed one of the buttons. When a button was pressed, the corresponding stimulus was highlighted for 0.4 s. The screen was then cleared, and feedback appeared on the screen's centre. In letters 32 pixels high, the word "CORRECT" or "WRONG", depending on the target and the participant's choice, was shown. The feedback lasted 0.75 s. The screen was then cleared and remained black for 0.25 s. Another stimulus pair was then presented.

Each of the four stimulus pairs was shown in every block of four trials. Preshift learning continued until participants selected the correct stimulus on 8 out of at most 10 consecutive trials (if a participant completed 100 trials of preshift learning without reaching criterion, the experiment was terminated, and the participant was replaced in the sample). When criterion was reached, learning was shifted to a novel target attribute.

For participants performing a RS, the other attribute of the initially relevant dimension became the target (e.g., a shift from *green* to *blue*). For participants performing a NS, learning was shifted to an attribute of the initially irrelevant dimension (e.g., a shift from *green* to *square*). For participants in Experiment 1A, there was no indication that the target had changed; only feedback to participants changed according to the new target. For participants in Experiment 2A, the new attributes were introduced in the shift-learning phase. The target for participants learning an IDS was an attribute of the initial dimension (e.g., a shift from *green* to *red*), while for participants learning a EDS it was an attribute from the originally irrelevant dimension (e.g., a shift from *green* to *hexagon*).

Shift learning continued until participants reached the 8 out of 10 success criterion, at which point the experiment terminated. If a participant completed 100 trials of postshift training without reaching criterion, the experiment terminated, and the participant was replaced in the sample. When the shift-learning task was terminated, participants were instructed to stop counting. Debriefing information was then presented on the computer. They were also informed that their voice had not been recorded.

During the experiment, the experimenter was seated in a chair behind and to the right of participants in order to monitor progress and compliance with instructions. The experimenter answered questions during the instruction phase, prompted participants to start counting if they failed to do so at the onset of the distractor task, prompted participants to start responding on the response box at the onset of the shift-learning task, and prompted participants to continue counting and/or responding if they paused either behaviour during the task. The experimenter noted whether participants counted improperly (i.e., that they failed to count backwards by steps of 3) and whether they paused counting for two or more successive learning trials. In either case, data from these participants were discarded, and they were replaced in the sample.

The procedure for participants in Experiments 1B and 2B was the same as that in Experiments 1A and 2A, respectively, with the exception that materials and references to the distractor were removed; participants only performed a continuous (Experiment 1B) or total change (Experiment 2B) shift-learning task.

Results

All participants comprising the final samples in Experiments 1A and 2A were able to complete both phases of the shift-learning task while performing the distractor task appropriately. Over the course of the experiment, however, it appeared that performing both tasks was relatively difficult (as assessed by the large number of participants that had to be replaced and through informal post-mortems with participants).[3] One participant in Experiment 1B reported failing to notice errors at the onset of the shift phase, thus responding by selecting the initial attribute for seven trials after reaching criterion in the first learning phase. Data from this participant were discarded. It also appeared that some participants required a large number of learning trials in control experiments 1B and 2B. Our first concern thus was with excessive variability in the data.

Figure 4 shows the number of trials to criterion for initial and shift-learning phases for control and distracted conditions. As can be seen, there are quite a few outliers for both measures in both conditions. These outliers were removed from subsequent quantitative analyses, regardless of which task they were learning and regardless of whether or not we expect specific group differences. However, when possible, we complemented parametric tests with nonparametric tests using the whole sample.

Table 1 summarizes the mean number of trials to criterion for the initial learning phase. The data are organized as a function of whether or not participants were distracted, whether the subsequent shift was within or between dimensions, and whether the same stimuli were used in both phases (continuous tasks) or not (total change tasks). While we expected the distracted participants to require more learning trials than would controls, a first step was to ensure that the groups were otherwise comparable at the onset of shift learning. The number of trials to criterion for the initial learning phase was analysed with a 2 (distracted) by 2 (dimension) by 2 (stimuli) analysis of variance (ANOVA). Neither the three-way interaction, $F(1, 20) = 2.289$, $p = .133$, nor any of the two-way interactions, all $Fs(1, 120) < 1.366$, $ps > .244$, reached significance. While

[3] This is not unexpected. For instance, Tsiakas and colleagues (2004) observed an increase in standard deviations in their Brown–Peterson conditions ranging from 5 to 12 times what they observed in control conditions.

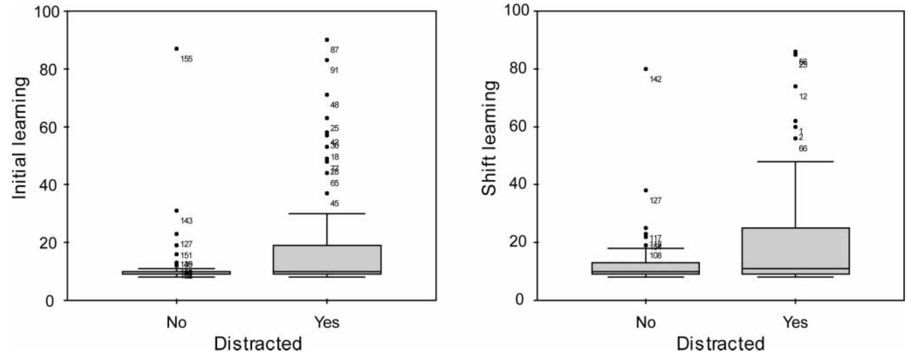

Figure 4. *Boxplots of number of trials to criterion for initial (left) and shift (right) learning phases.*

distraction significantly increased initial learning trials, $F(1, 120) = 16.465$, $p < .001$, there were appropriately no effects of dimension or stimuli, $Fs(1, 120) < 0.752$, $ps > .387$. Thus, with the obvious exception of distraction, the groups were comparable at the end of initial training.

The mean number of trials to criterion in the shift-learning phase are summarized in Table 2. Again, the data are organized as a function of distraction, shift dimension, and stimuli. The number of trials to criterion for the shift-learning phase was also analysed with a 2 (distracted) by 2 (dimension) by 2 (stimuli) ANOVA. The three-way interaction did not reach significance, $F(1, 120) = 0.193$, $p = .661$, nor did the Distracted × Dimension, $F(1, 120) = 1.067$, $p = .304$, and Dimension × Stimuli, $F(1, 120) = 0.485$, $p = .488$, two-way interactions. However, the Distracted × Stimuli interaction was significant, $F(1, 120) = 3.910$, $p < .05$, so we examine simple main effects for each factor.

Table 1. *Mean trials to criterion for the initial learning phase of Experiments 1A, 1B, 2A, and 2B*

	Distracted				*Control*			
	Within		*Between*		*Within*		*Between*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Continuous	14.0	4.67	12.0	4.56	9.1	0.79	9.3	1.03
Total change	10.6	4.19	12.7	6.33	9.4	0.84	9.1	0.87

Note: Groups are defined by the presence or absence of a distractor task, by a shift within or between dimensions, and by paradigm (continuous vs. total change).

In the absence of a distractor task, participants required 10.0 trials ($SD = 2.21$) to learn the shift when the stimuli were novel, relative to 10.7 trials ($SD = 1.43$) when the stimuli were the same as those in the initial learning phase. This difference is not significant, $t(43) = 1.412$, $p = .165$, $d = 0.4237$. When a distractor was present, participants required 12.2 trials ($SD = 7.90$) to learn the shift when the stimuli were novel and 18.0 trials ($SD = 8.72$) when the stimuli were unchanged. This difference is significant, $t(81) = 3.153$, $p < .01$, $d = 0.6947$. When stimuli remain the same in both phases of the experiments, distracted participants ($M = 18.0$, $SD = 8.72$) required more trials to reach criterion than did control participants ($M = 10.7$, $SD = 1.43$), a difference that reaches significance, $t(61) = 4.126$, $p < .001$, $d = 1.0626$. When stimuli changed in the shift-learning phase, distracted ($M = 12.2$, $SD = 7.90$) and control participants ($M = 10.0$, $SD = 2.21$) did not significantly differ from one another, $t(63) = 1.272$, $p = .208$, $d = 0.3418$. Finally, the ANOVA reveals a significant effect of dimension, $F(1, 120) = 4.620$, $p < .05$, suggesting that, overall, shifts within the original dimension ($M = 11.9$, $SD = 5.68$) were learned quicker

Table 2. *Mean trials to criterion for the shift-learning phase of Experiments 1A, 1B, 2A, and 2B*

	Distracted					*Control*				
	Within		*Between*			*Within*		*Between*		
	M	*SD*	*M*	*SD*	*d*	*M*	*SD*	*M*	*SD*	*d*
Continuous	16.8	7.73	19.3	9.75	0.2897	10.2	1.11	11.2	1.54	0.7877*
Total change	9.75	3.18	15.1	10.47	0.7116*	9.1	0.87	10.8	2.82	0.8140*

Note: Groups are defined by the presence or absence of a distractor task, by a shift within or between dimensions, and by paradigm (continuous vs. total change). Effect sizes (d) are for comparisons of shifts within and between dimensions for each paradigm and distraction level.

* Within–between difference has $p < .05$.

than shifts between dimensions ($M = 14.8$, $SD = 8.69$).

In order to relate our results more clearly to the hypotheses and to prior work, we performed pairwise comparisons between shift dimension (within vs. between) for each of the four experiments (see Table 2). In the absence of a distractor (Experiment 1B), a RS was learned quicker than a NS, $t(23) = 1.968$, $p < .05$, one-tailed, $d = 0.7877$, as expected. However, with the distractor task (Experiment 1A), the difference was not significant, $t(36) = 0.892$, $p = .379$, $d = 0.2897$. As anticipated, an IDS was learned quicker than an EDS, whether participants were distracted, $t(43) = 2.381$, $p < .05$, one-tailed, $d = 0.7116$ (Experiment 2A), or not, $t(18) = 1.820$, $p < .05$, one-tailed, $d = 0.8140$.

As the pairwise comparisons for distracted conditions are the crucial tests of the predictions, we complement them using the equivalent nonparametric procedure (i.e., the Mann–Whitney U test) with all participants. This helps ensure that our results are not unduly affected by the removal of outliers. In Experiment 1A, we found no significant differences on initial learning ($U = 241.0$, $z = -1.394$, $p = .163$), and no differences on shift learning ($U = 232.5$, $z = -1.556$, $p = .120$) between the RS and NS groups. In Experiment 2A, we found no significant difference on initial learning ($U = 198.5$, $z = -0.740$, $p = .459$), but a significant difference on shift learning ($U = 113.00$, $z = -3.934$, $p < .001$). The mean rank for the IDS group (20.8), relative to the mean rank of the EDS group (23.6), is consistent with the relative ease of IDS over EDS. In the control experiments (1B and 2B), there were too few unique scores (5 and 6, respectively) for the procedure to be applied (Huber & Wagner–Döbler, 2003).

Discussion

We observed that the distractor task interacted with the type of stimuli used in the shift-learning phase (same or novel). In the absence of distraction, there was no advantage of total change tasks over continuous tasks. However, with distraction, total change tasks were markedly easier. Indeed, distracted participants in total change tasks did not differ from controls, whereas distracted participants in continuous tasks required significantly more trials than their controls to learn a category shift. We also observed an overall effect of shift dimension, whereby shifts within the initial dimension are easier than shifts between dimensions. When we examined this latter effect in each experiment, the results provided unequivocal support for our suggestion that adult shift learning is a function of extensive, covert processing.

The use of a distractor task in a continuous shift-learning task (Experiment 1A) prevented adults from learning a RS significantly faster than a NS. The two shifts were learned equally quickly, and as such the participants' performance is similar to what we would expect to observe in preschoolers.[4] This supports the hypothesis that the usual performance of older children and adults, compared to preschoolers, is a function of amount of iterative processing during discreet trials. Importantly, the distractor task did not prevent participants from reaching the relatively strict criterion in the preshift and shift-learning phases. Learning thus took place, but positive transfer from preshift learning was prevented.

In Experiment 1B, participants performing a RS required significantly fewer trials than did participants learning a NS. These results replicate the typical ease of RS over NS, which has been extensively documented (Esposito, 1975; Wolff, 1967). We can assume that our implementation of the shift-learning procedure in Experiment 1A was adequate.

Of course, one potential confound is that the increased variance in Experiment 1A, due to the distractor task, may mask a larger effect than that in Experiment 1B, which reaches significance because variance is substantially less. Two remarks are pertinent to this issue. First, it is interesting to note that Cole (1973, 1976) has argued that shift learning in preschoolers is highly variable as well (both within and between children). If we claim to reproduce preschool performance in Experiment 1, increased variance is desirable. Second, one likely significant contributor to the larger difference in means in Experiment 1 is that very variance. It is thus counterproductive to ignore variance when examining mean differences and to suggest that there is a *stronger* effect in Experiment 1A than in Experiment 1B. Indeed, when we consider effect sizes, we find that the standardized difference in means is more than twice as large in Experiment 1B as in Experiment 1A.[5]

It remains that the distractor task in Experiment 1A either interfered mainly with iterative processing and produced preschool-type learning performance in adults, as hypothesized, or alternatively hindered discriminative learning directly, increasing variance and masking positive transfer. If Experiment 1A did indeed produce preschool-like behaviour in adults, we should see positive transfer with the same distractor on a total change task. However, if the distractor merely hindered learning, we should see a lack of positive transfer in total change tasks as well.

The use of a distractor task in a total change task (Experiment 2A) did not prevent adults from exhibiting positive transfer in the shift-learning phase, unlike in Experiment 1A, thus learning an IDS quicker than an EDS. This performance is consistent with the performance of both preschoolers and adults engaging in such a learning task in the absence of a distractor. However, it is the divergence in results between Experiments 1A and 2A that allows us to suggest that adults performed as preschoolers and raises problems for alternative accounts.

If the distractor task affected learning per se, preventing adults from appropriately identifying the relevant dimension and the relevant attribute within this dimension, then hindered positive transfer would be observed in both Experiments 1A and 2A. Arguments that attempt to accommodate the mediational or differentiation accounts for the results from Experiment 1A are inconsistent with the results from Experiment 2A. If, however, the distractor task mainly hindered the ability to engage in iterative processing, the results from Experiment 2A are consistent with attentional mediation, perceptual differentiation, and spontaneous overtraining interpretations. However, only spontaneous overtraining is

[4] Interestingly, the mean number of trials to criterion in the preshift phase (13.1, $SD = 4.67$) is similar to what we observe in young children. From data in a discriminative-learning experiment using woodblocks that vary in shape and colour, 3- to 6-year-olds require a mean number of trials to criterion of 15.1 ($SD = 8.38$, $n = 236$) for an initial discrimination (Sirois, 2005). Our distracted adults do not differ from these children, $t(272) = 1.447$, $p = .149$, $d = 0.2507$.

[5] A related issue is that for the motivated, competent learner, RS and NS are trivially easy tasks. On average, solving the NS will only take between 1 and 2 more trials than solving the RS. It is thus consistent with a robust effect that it occurs, as here, with a small sample.

consistent with the divergent results from Experiments 1A and 2A. Except for the spontaneous overtraining interpretation, other accounts either cannot explain Experiment 1A or would lose the ability to explain Experiment 2A while accommodating the results from Experiment 1A.

Finally, participants performing the IDS required significantly fewer shift-learning trials than did those learning an EDS in the absence of a distractor task. These results replicate the typical ease of IDS, which is well documented (Esposito, 1975; Wolff, 1967). Our implementation of the shift-learning procedure in Experiment 2A was thus adequate.

We thus observe significant differences and large standardized effects where expected (Experiments 1B, 2A, and 2B), and not where they were not expected (Experiment 1A). It remains that the standardized effect of Experiment 1A is small, bordering on medium (Cohen, 1988), despite not reaching significance. Of course, as we argue that differences between young children and adults are a matter of degree and not kind, we could be satisfied with this pattern of effects. Yet if we compute replication probabilities (Killeen, 2005), we obtain values of .72, .90, .95, and .88 for Experiments 1A, 1B, 2A, and 2B, respectively. These imply that for the latter three experiments we can reasonably expect to replicate these significant shift-learning differences with similar or larger samples. However, for Experiment 1A, a significant difference (i.e., dimensional transfer) should remain elusive even with a large ($n > 100$) sample (see Killeen, 2005, for details of the statistical procedure).

Still, it would be more convincing if we could strongly show a lack of positive transfer in continuous tasks. Fortunately, optional shift tasks allow us to examine transfer (or lack thereof) independently of considerations about effect size or variability. In these tasks, participants are categorized as *reversers* or *nonreversers* as a function of their performance on test items that assess transfer. Prior research provides empirical benchmarks for preschoolers and adults, which we can use to assess whether distracted adults do behave as preschoolers.

EXPERIMENT 3: OPTIONAL SHIFT LEARNING WITH A COGNITIVE LOAD

In the initial learning phase of the OS task (Figure 3), participants learn a discrimination task with four pairs of stimuli, as we have used in the initial learning phase of Experiments 1 and 2. When criterion is reached, a partial shift-learning phase begins with two of the original four pairs of stimuli. The two pairs are selected such that the shift could be within the original dimension (i.e., *square* to *circle*) or between dimensions (i.e., from *square* to *black*). Training continues until criterion is reached, at which point the test phase begins with all four stimulus pairs. The main question is whether participants generalize the shift to the stimulus pairs not used during shift learning (the test pairs).

When participants reliably change their initial answer for these test pairs—a generalization of the shift-learning phase that is consistent with a reversal shift—they are labelled *reversers.* Participants whose performance on the test pairs is not consistent with a reversal shift are labelled *nonreversers.* The majority of preschoolers are labelled *nonreversers* on this task and with this asymmetrical scoring procedure, while the majority of adults behave as *reversers* (T. S. Kendler, 1983). According to the spontaneous overtraining hypothesis, the majority of adults should be labelled *nonreversers* when spontaneous overtraining is blocked.

Method

Participants

Experiment 3A. The 20 participants in this experiment were psychology undergraduates from the University of Manchester. They took part in the experiment in exchange for course credit. The sample consisted of 14 females and 6 males.

Mean age of participants was 20.4 years (SD = 5.61).

Experiment 3B. The 20 participants in this experiment were psychology undergraduates from the University of Manchester and took part in exchange for course credit. The sample comprised 18 females and 2 males. The mean age of participants was 19.4 years (SD = 1.39).

Apparatus

The optional shift task was presented on an IBM-compatible desktop computer. The 15″ screen of the computer was set at a resolution of 800 by 600 pixels, with black as the background colour. The stimuli used for the experiment were the same as those in Experiments 1A and 1B (and as in the initial learning phase of Experiments 2A and 2B).

The computer was used to present instructions to participants and to administer the shift-learning task. The computer randomly selected the initial attribute and the two shift training stimulus pairs. The experiment was programmed in E-Prime, and a serial response box (from Psychology Software Tools) was used to record answers.

Procedure

The same procedure as that in Experiment 1 was used, except for the shift-learning phase. In this experiment, shift learning only used half of the four stimulus pairs, and a test phase used all four stimulus pairs. In the test phase, the four stimulus pairs were presented only once, in random order. Participants who generalized shift learning to both tests items were labelled *reversers*, whereas participants who failed to generalize to both test items were labelled *nonreversers.* This asymmetry (i.e., strictly reverser vs. other) is necessary to compare our data to benchmarks from the literature (see Footnote 1). At the end of the experiment, participants were debriefed.

Participants in Experiment 3A performed the optional shift task simultaneously with the Brown−Peterson task. They received the same instructions about the distractor as did participants in Experiments 1A and 2A. Participants in Experiment 3B only performed the optional shift-learning task.

Results

Experiment 3A

The mean number of trials to reach criterion in the initial and shift-learning phases were 14.75 (SD = 6.89) and 15.25 (SD = 15.113), respectively. Of the 20 participants, 13 were labelled *nonreversers.* This was compared to the empirical benchmark of 80% nonreversers for preschoolers (T. S. Kendler, 1983) and was found not to be significantly different, $\chi^2(1, N = 20) = 2.813$, *ns.* The results were a significant departure from the usual 13% nonreversers in adults, $\chi^2(1, N = 20) = 47.816, p < .001$. Figure 5 plots the expected and observed numbers of reversers and nonreversers, assuming that distracted adults perform like preschoolers. Removing outliers (n = 3) based on number of initial or shift-learning trials does not affect the pattern or significance of results.

Experiment 3B

The mean number of trials to reach criterion in the initial and shift-learning phases were 15.45 (SD = 19.44) and 10.2 (SD = 0.89), respectively. Of the 20 participants, 17 were labelled *reversers.* Compared to the empirical benchmark of 87% reversers for adults (T. S. Kendler, 1983), this was not found to be significantly different, $\chi^2(1, N = 20) = 0.071$, *ns.* The results were a

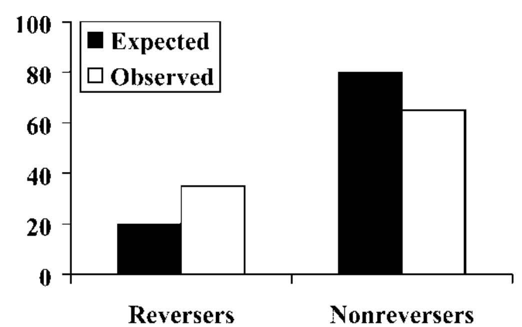

Figure 5. *Percentages of reversers and nonreversers in distracted adults (observed) and preschoolers (expected, from T. S. Kendler, 1983).*

significant departure from the usual 20% reversers in preschoolers, $\chi^2(1, N = 20) = 52.813$, $p < .001$. Figure 6 plots the expected and observed numbers of reversers and nonreversers for adults. Removing the single outlier in the sample (97 learning trials in the initial phase) did not alter the pattern or significance of results.

Discussion

Participants performing the OS task simultaneously with the Brown–Peterson task showed preschool performance on test pairs. The proportion of participants who failed to show positive transfer to test items is comparable to what can be expected from preschoolers and very much unlike what adults typically do. This lends additional support to the suggestion that the results of Experiment 1A reflect preschool-level processing in distracted adults.

Participants performing only the OS task replicated the typical pattern of performance of adults, with a large majority exhibiting positive transfer from shift learning on test items. This suggests that our implementation of the OS task was suitable and as such that the preschool level of performance in Experiment 3A was indeed due to the presence of a distractor task.

GENERAL DISCUSSION

A key assumption of the spontaneous overtraining hypothesis is that older children and adults engage

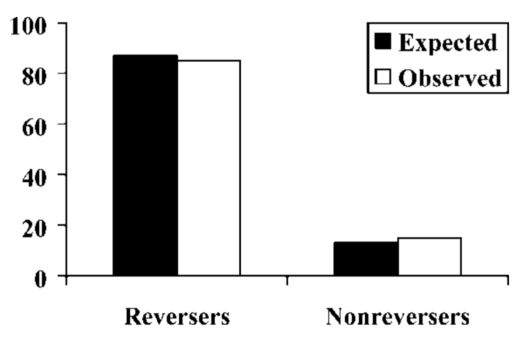

Figure 6. *Percentages of reversers and nonreversers in adults (observed) and as expected (from Kendler, 1983).*

in more extensive covert processing of the discriminative learning task information than younger children do (Sirois & Shultz, 1998a, 1998b). Furthermore, it is this quantitative increase in processing that produces a qualitatively different pattern of behaviour in adults as compared to preschoolers. The results from Experiments 1A, 2A, and 3A support this interpretation of shift-learning performance. By blocking rehearsal with a Brown–Peterson distractor task, adult participants executed reversal and nonreversal shifts equally fast and exhibited nonreversal behaviour on the optional shift task, yet showed positive transfer on intradimensional shifts. We suggest that the distractor task interferes with focused learning of the relevant information, as we assume to be the case in preschoolers, impairing positive transfer from initial learning when the same stimulus attributes are used in the shift-learning phase. Informal postmortems suggest that distracted participants were unable to identify the target attributes, despite learning to criterion. This is also consistent with our interpretation of preschooler performance (e.g., Sirois, 2002, discussed later) and is worthy of further, systematic investigation.

The results from Experiments 1B, 2B, and 3B suggest that our implementations of the shift-learning tasks were adequate, reproducing the typical relative ease of RS over NS, ease of IDS over EDS, and reversal behaviour on the OS task when the distractor is not used. The preschool-like performance in Experiments 1A and 3A is thus not a function of the specific discrimination shift procedures that we used.

Although none of the individual experiments was devised as comparative tests of all discrimination shift interpretations, it is worth considering how other models might account for the overall pattern of data. The levels-of-processing approach of the Kendlers could predict preschool performance by adults in the distractor task. Indeed, the Brown–Peterson task could prevent the use of intermediate, categorical responses because participants would be unable to use the appropriate labels while counting. Participants could thus learn only simple associations, as would preschoolers.

The problem is that preschoolers (or adults functioning as preschoolers), according to the levels-of-processing approach, would execute the nonreversal shift quicker than the reversal shift (H. H. Kendler & Kendler, 1975; T. S. Kendler, 1983), which our data do not support. Thus results from Experiment 1A are at odds with their theory. Also, as outlined earlier, the Kendlers' approach cannot accommodate positive transfer in total change experiments, whether for adults or for children. Finally, results from Experiment 3A are consistent with the Kendler view. Nevertheless, overall results are inconsistent with the levels-of-processing interpretation.

The attentional model of Zeaman and House (1974, 1984) is also at odds with our results. The Brown–Peterson task requires attentional resources, which could hinder the contribution of the intermediate attentional responses to overt behaviour, as in Experiments 1A and 3A. However, we see positive transfer in Experiment 2A, despite the same distractor task. Such transfer is from initial learning, which is identical in all three dual-task experiments. This is exactly the problem that historically plagued the attentional model (Sirois & Shultz, 1998a). It predicts positive transfer for adults in both continuous and total change tasks, yet only works for preschoolers on total change tasks because they do not show transfer on continuous tasks. Zeaman and House (1984) blamed intermittent reinforcement, to which preschoolers were deemed more susceptible, for the lack of transfer on continuous change tasks. A similar argument would be required to explain our data, consistent with our view that we produce preschool-like behaviour in adults. However, attentional mediation would still be at odds with Experiment 1A because the argument was typically made to explain the relative ease of NS over RS, which the literature and our data do not actually support.

L. S. Tighe and Tighe's (1966a) and T. J. Tighe and Tighe's (1978) perceptual differentiation interpretation is also incompatible with our results. Their model suggests that older children's and adult's performance patterns are a function of prior perceptual experience, lacking (in quantity) in preschoolers. Whereas the Brown–Peterson task may hinder normal processing, participants nevertheless learned preshift and shift discriminations to criterion. It is unclear how the distractor task could have prevented prior perceptual experience from playing a role in a perceptual learning task, especially in the light of positive transfer in Experiment 2A. If we are strict, Tighe and Tighe's theory is only consistent with Experiment 2A. However, if we are lenient and suggest that the distractor deprived participants of perceptual processing resources, rendering them equivalent to preschoolers, then Tighe and Tighe remain at odds with Experiment 1A, predicting relative ease of nonreversal shifts, despite accommodating experiments 2A and 3A.[6]

Table 3 lists the ability of each theoretical model to account for various discrimination shift psychological regularities, including Experiments 1A, 2A, and 3A. The spontaneous overtraining interpretation stands out as the most comprehensive.

We are currently investigating another prediction of the spontaneous overtraining hypothesis: namely, that preschoolers would perform at chance level on a classification task following a discriminative learning task. Our simulations (Sirois & Shultz, 1998a, 1998b) suggest that so-called *perceptual compounds* in preschoolers (i.e., responding to the stimulus as a perceptual whole) are at the level of stimulus pairs and not individual stimuli (e.g., L. S. Tighe & Tighe, 1966a; T. S. Kendler, 1983). If learned behaviour is thus a function of stimulus pairs, as we suggest, learning should not transfer to individual stimuli in a testing phase. Our preliminary results with preschoolers support this suggestion (Sirois, 2002, 2005). From

[6] Aside from the relative merits of the spontaneous overtraining model, one clear conclusion is that it is relatively easier to derive predictions from computational models (such as those that we initially devised to test the spontaneous overtraining interpretation) than from verbal theories. Computational models need a level of specification that is typically absent in verbal or flowchart models, and which makes the derivation of precise predictions much easier (Shultz, 2003).

Table 3. *Psychological regularities accounted for by the different models*

	Model			
Regularity	*Conceptual mediation*	*Attentional mediation*	*Perceptual differentiation*	*Spontaneous overtraining*
Adult RS < NS	Yes	Yes	Yes	Yes[a]
Adult IDS < EDS	No	Yes	Yes	Yes[b]
Adult optional shift	Yes	Yes	Yes	Yes[a]
Child RS = NS	No	No	No	Yes[a]
Child IDS < EDS	No	Yes	Yes	Yes[b]
Child optional shift	Yes	No	Yes	Yes[a]
Experiment 1A	No	No	No	Yes
Experiment 2A	No	Yes	Yes	Yes
Experiment 3A	Yes	Maybe	Maybe	Yes

[a]Sirois and Shultz (1998a). [b]Sirois and Shultz (1998b).

postmortems in Experiment 1A, we would expect similar results with adults who perform discriminative learning concurrently with a distractor task. While these adults perform the task to at least 80% correct by criterion, they could not explicitly identify the target of the discrimination.

Dimensionless shift-learning tasks represented a pitfall for all three prior theoretical accounts and would be another natural next step to evaluate the spontaneous overtraining interpretation. In such experiments, four unrelated stimuli are arbitrarily assigned reward contingencies such as those found in usual discrimination shift experiments. The stimuli are presented pairwise for initial learning. When a success criterion is reached, a change in reward contingencies is introduced. A full reversal implies changing all responses to all pairs (akin to a RS), whereas a half reversal involves changing only half of the initial responses (akin to a NS). Bogartz (1965) observed that full reversals were easier than half reversals for adults, whereas Goulet and Williams (1970) replicated the typical discrimination shift ontogeny with children using such tasks. Because the stimuli in such experiments cannot be categorized based on perceptual dimensions, none of the three leading theoretical interpretations can account for the data. Showing that distracted adults perform as preschoolers on this task as well would provide exclusive additional support to the spontaneous overtraining interpretation.[7]

More generally, data from discrimination shift tasks have been used to argue that preschoolers hold radically different representations from those of older children and adults (e.g., T. S. Kendler, 1983, 1995). This may be true for a variety of higher order concepts (e.g., Karmiloff-Smith, 1992). With respect to simple perceptual discriminations, however, our work so far suggests that quantity, rather than quality, may be the better qualifier. Whereas the overtraining literature suggests that young children can perform in a similar fashion to adults, we have shown how adults can be made to perform like preschoolers as well. In the light of this symmetry, the suggestion that both groups hold radically different types of representation does not appear appropriate for these basic tasks.

Rather than propose two different explanations to account for preschool and adult performance, with development from one to the other, which can be circumvented by some overtraining, we

[7] We felt that a priority, however, was to first show the worth of the spontaneous overtraining interpretation on standard shift-learning tasks, for which there is a more substantial and robust literature.

propose a single associative mechanism that is sensitive to quantitative changes in information to be processed. The overtraining literature provides the first part of the support for a continuity of representations between preschoolers and adults. The results of the experiments reported in this paper provide the second, necessary part of support by showing the bidirectional nature of this continuity. Our interpretation is simpler, yet provides better coverage. Recent work on categorization suggests a similar continuity of representations from infancy to adulthood (Gureckis & Love, 2004).

This suggestion is partially compatible with the COVIS theory of Ashby and colleagues (Ashby, Alfonso-Reese, Turken, & Waldron, 1998). The COVIS theory ("competition between verbal and implicit systems") proposes that category learning is a competition between a verbal, explicit learning system and a nonverbal, implicit system. The explicit system is mediated by frontal brain areas (i.e., anterior cingulate, prefrontal cortex, and the head of the caudate nucleus), while the implicit system is mediated by subcortical structures (i.e., the tail of the caudate nucleus and a dopamine-mediated reward signal). The theory has been successfully tested on a variety of categorization tasks (see Maddox & Ashby, 2004, for a discussion). Our results suggest that the distractor task interfered with the explicit system, forcing participants to rely more on the implicit system (which preschoolers probably rely on more as well, because of underdeveloped frontal lobes, hence the similar pattern of performance).

We must note two departures from the COVIS theory, though. In COVIS, the explicit system is based on transient processes that involve attention and working memory. While this is fine, it leaves open the question of long-term storage of explicit information. The review by Maddox and Ashby (2004), for instance, does not address storage in the explicit system despite doing so for the implicit system. Rather than propose a third system for long-term storage, we suggest that the explicit system merely biases the input to the implicit system (for a similar short-term, long-term, dual-system interpretation of infant habituation, see Sirois & Mareschal, 2004). Also, shift-learning tasks such as those used in this paper are best thought of as classical conditioning tasks in the absence of explicit processing. Such tasks are deemed to rely on cerebellar rather than subcortical structures (see Nelson, 2002, for a review). While our research was not designed as a test of COVIS, we suggest that a potential extension of that model is one where the explicit system biases information processing when verbal rules can be used and where varied implicit systems carry out the actual information storage, susceptible to the bias introduced by the use of the explicit system (see also the review paper by Ashby & O'Brien, 2005, for a related discussion).

As a final observation, research with elderly adults has shown that shift-learning performance seems to revert to preschool level in old age (Nehrke & Coppinger, 1971; Shanab & McClure, 1983; Witte, 1971). There is also support for the suggestion that rehearsal decreases in old age (e.g., Dulaney, Marks, & Link, 2004; Hasher & Zacks, 1979; Jennings, Nebes, & Brock, 1988; Ward & Maylor, 2005). To the best of our knowledge, there is no published work on overtraining in discrimination shifts with the elderly. It is thus worthy of further investigation that the spontaneous overtraining hypothesis would naturally predict normal adult performance in overtrained elderly participants.

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