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Investigating the effects of pretraining associations between compound-stimulus elements on stimulus overselectivity

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ABSTRACT

When a compound stimulus comprising multiple elements signals the contingencies for responding, not all those elements necessarily come to control behavior. Previous research suggests that such *stimulus overselectivity* depends on the strength of the associations between the elements, with stronger within-compound associations attenuating overselectivity. We investigated whether establishing associations between stimulus elements in a separate pretraining phase would modulate overselectivity. During pretraining, 384 adult human participants completed a matching-to-sample task in which associations between elements were trained directly, indirectly via many-to-one training, or not at all. Then, they chose between two compound stimuli composed of pretrained elements, or of novel elements, in a simultaneous-discrimination task. Overselectivity was assessed by measuring choice of individual stimulus elements in an unreinforced test phase. There were no significant differences in overselectivity levels depending on pretraining history, perhaps because the effects of pretraining did not generalize or the type of association formed during pretraining differed from the within-compound associations that modulate overselectivity. Nevertheless, overselectivity did tend to be lower when elements had been associated together directly or indirectly, providing some preliminary evidence that pretraining associations may reduce overselectivity. Overall, the present study highlights the need for further work to establish the generality of our findings, and to identify the boundary conditions under which prior experience with individual stimulus elements does, or does not, modulate stimulus overselectivity.

1. Introduction

The term *stimulus control* describes the extent to which behavior varies in the presence of different stimuli (Morse & Skinner, 1958; Terrace, 1966): When instrumental (operant) behavior is differentially reinforced in the presence of different antecedent stimuli, those stimuli may come to determine the occurrence of the behavior (i.e., the behavior occurs in the presence of stimuli signaling reinforcer availability, and not in the presence of stimuli signaling the absence of reinforcers). Behavior may also come under the control of multiple stimuli, especially when more than one stimulus nonredundantly signals the contingencies for responding. Such *complex stimulus control* is considered "pivotal" (Koegel et al., 1989, p. 10) for learning and behavior across a range of domains, including

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motor, linguistic, social, emotional, cognitive, and academic development (Ploog, 2010). For example, skills such as coordinating movements, language learning, socializing with others, recognizing emotions, and following instructions all require some degree of control by more than one stimulus.[1]

However, the presence of multiple stimuli does not guarantee that all of those stimuli will control behavior. Under some circumstances, only one stimulus may control behavior at the expense of control by other relevant stimuli (Lovaas et al., 1971, 1979; Ploog, 2010). Such *stimulus overselectivity*[2] can hinder acquisition, maintenance, and/or generalization (Ploog, 2010); for instance, Schreibman and Lovaas (1973) showed that children with autism spectrum disorder (ASD) could learn to discriminate between clothed boy and girl dolls, but the discrimination did not generalize if the heads or clothes of the dolls were interchanged, suggesting that the children had learned to discriminate on the basis of only a single feature (e.g., clothing). A large body of research shows that overselectivity occurs in individuals with ASD and other developmental or intellectual disabilities (e.g., Butler & Rabinowitz, 1981; Frankel et al., 1984; Kelly et al., 2015; Koegel & Schreibman, 1977; Koegel & Wilhelm, 1973; Kolko et al., 1980; Lovaas et al., 1971; Matthews et al., 2001; Reed, 2012; Rincover & Ducharme, 1987; Schreibman & Lovaas, 1973), as well as in preschool-aged children (Eimas, 1969; Kelly & Reed, 2020; Reed et al., 2013), elderly adults (Kelly et al., 2016; McHugh & Reed, 2007; McHugh et al., 2010), and healthy younger adults under conditions of high cognitive load (e.g., Broomfield et al., 2010; Gomes-Ng et al., 2023, 2025; Reed & Gibson, 2005; Reed, Reynolds, & Fermandel, 2012; Reynolds & Reed, 2018). Therefore, research investigating stimulus overselectivity is relevant to understanding the mechanisms that underpin discrimination learning in a range of populations.

The typical procedure for studying stimulus overselectivity involves a discrimination-learning task (e.g., simultaneous discrimination or matching to sample) with compound (multi-elemental) stimuli, followed by an unreinforced testing phase in which responding to the individual compound-stimulus elements is recorded (e.g., Broomfield et al., 2010; Gomes-Ng et al., 2023, 2025; Kelly & Reed, 2020; Reynolds & Reed, 2018). For example, in the simultaneous-discrimination procedure, choice of a compound S+ stimulus (e.g., AB), but not of a compound S- stimulus (CD), is reinforced. Once participants reliably choose the correct compound, they are presented with a choice between an S+ and S- element (e.g., A vs. C) during testing. The frequency of choice of each element is taken as a measure of the strength of control by that element. Overselectivity is said to occur when one S+ element is selected more frequently than the other S+ element during testing (e.g., element A > element B), with larger differences between the elements reflecting greater overselectivity.

Early theoretical accounts proposed that overselectivity reflects an attention deficit, in the sense that some stimuli are not observed or attended to during learning and hence do not control behavior (e.g., Lovaas et al., 1971, 1979). In support of this, some studies have found that stimuli observed for longer exert stronger behavioral control, and that overselectivity may be reduced by differentially reinforcing observing responses to each stimulus (see e.g., Dube & McIlvane, 1999; Dube et al., 1999, 2003, 2010; Reed, Altweck, et al., 2012). Alternatively, more recent research has drawn conceptual and mechanistic parallels between overselectivity and the widely studied Pavlovian phenomenon of overshadowing (e.g., Reed & Quigley, 2019; Reynolds & Reed, 2018). Like overselectivity, overshadowing involves unequal control by the elements of a compound stimulus; the key distinction between these phenomena is that overselectivity is defined in terms of the difference in control between compound-stimulus elements, whereas overshadowing is assessed relative to a control condition in which an element is trained alone (e.g., after conditioning with compound AX, overshadowing occurs if element X elicits a weaker response than when X is conditioned alone). Additionally, relative differences in stimulus salience (e.g., brightness, loudness) are central to overshadowing effects, but not necessarily to overselectivity (but see Leader et al., 2009, who found effects of salience on overselectivity). Despite these differences in the conditions that establish overselectivity and overshadowing, some evidence suggests that both phenomena may reflect competition between stimulus elements at the time of performance or retrieval. According to this account, all stimuli are attended to and learned about during acquisition, but this learning is not always expressed behaviorally due to competition for control between the stimuli at the time of retrieval (i.e., during testing in the overselectivity procedure).

One such performance-deficit account is *comparator* theory, which asserts that associations between each element and trial outcomes, and between elements compounded together, develop during discrimination learning. The relative strength of these associations determines which element(s) exert behavioral control: If, for instance, element A is more strongly associated with reinforcement than element B, then A will be ‘selected’ (via a ‘comparator’ mechanism) to control behavior at the expense of control by B (Reed, 2011; Reed & Quigley, 2019; see also Escobar et al., 2024; Miller & Matzel, 1988; Miller & Witnauer, 2016). Importantly, because subjects do learn about element B (i.e., the underselected or overshadowed element), a key prediction of comparator theory is that control by that element may subsequently emerge if the association between element A and trial outcomes is weakened. This prediction has been supported empirically in both studies of overshadowing and overselectivity: Extinguishing the compound-stimulus element that exerts stronger control can increase control by the other element (*retrospective revaluation*; e.g., Broomfield et al., 2010; De Houwer & Beckers, 2002; Gomes-Ng et al., 2023, 2025; Kaufman & Bolles, 1981; Kelly et al., 2015; Matzel et al., 1985; Miller & Witnauer, 2016; Reed et al., 2009; Reed, Reynolds, & Fermandel, 2012; Reynolds et al., 2012; Wasserman & Berglan, 1998).

An important component of comparator theory is the associations that form between the elements of the compound stimulus. These within-compound associations modulate the degree of overselectivity (or overshadowing), such that stronger associations between the

[1] Although we only investigate control by operant discriminative stimuli in the present paper, stimulus control also extends to Pavlovian procedures, in which a conditioned stimulus elicits a conditioned response.

[2] The term “overselectivity” implies that selective stimulus control is maladaptive. This may not always be the case; for instance, driving behavior generally comes under the control of the color of traffic lights and not their vertical location, and this is efficient rather than problematic. Nonetheless, we will use the term “overselectivity” in this paper, rather than simply “selectivity”, because it is the norm in this literature.

elements attenuate overselectivity. According to comparator theory, this occurs because each element more effectively activates an internal 'representation' of the other element, thereby reducing competition for behavioral control. Consistent with this account, overselectivity and overshadowing are both less likely when more training trials are arranged (Huguenin, 2000, 2004; Reed & Quigley, 2019; Reynolds & Reed, 2011; Schover & Newsom, 1976) or when compound stimuli are presented for longer durations (e.g., Reynolds & Reed, 2018; Sissons et al., 2009; Urushihara et al., 2004; Westbrook et al., 1983). Both manipulations increase experience with the compound stimuli (e.g., increased pairings of A and B), which is thought to strengthen within-compound associations and thereby reduce overselectivity.

Despite the clear importance of within-compound associations in modulating stimulus overselectivity, one manipulation that has received little attention is explicitly establishing associations between the stimulus elements before they are compounded together. For example, pre-establishing an association between elements A and B may reduce the likelihood of overselectivity when those elements are later presented together as a compound. In support of this line of reasoning, Amundson et al. (2008) showed that in a Pavlovian conditioning procedure, establishing inhibitory associations between stimulus elements A and X (by presenting separate unreinforced AC and XC trials, such that A signals the absence of X and vice versa, and the elements are paired via common element C) reduced overshadowing when elements A and X were later compounded together, relative to when no associations had been previously established. The present experiment aimed to investigate whether this is also the case in an overselectivity procedure; specifically, we asked whether pretraining associations between stimulus elements directly (e.g., elements are presented simultaneously) or indirectly (e.g., via a common element, as in Amundson et al., 2008) would reduce stimulus overselectivity.

One operant procedure for training stimulus-stimulus associations is the *matching-to-sample* (MTS) task, in which subjects learn to match a 'sample' stimulus to a 'comparison' stimulus. This procedure has been widely used to establish relations between stimuli directly (e.g., two stimuli are matched together) and indirectly (e.g., two stimuli are each matched to a common stimulus; see e.g., Fields et al., 1984; Minster et al., 2011; Tonneau, 2001). Moreover, some evidence suggests that strength of such associations appears to be comparable to those formed in Pavlovian-type procedures, in which stimuli are presented together but no response is required (e.g., Clayton & Hayes, 2004; Kinloch et al., 2013). Thus, we based our pretraining procedure on the well-established stimulus-equivalence paradigm, because it provides a reliable operant method for establishing stimulus-stimulus associations. In this paradigm, relations between stimuli are trained directly (e.g., matching A to B) or indirectly (e.g., matching A to M and B to M), and the existence of these relations is then tested by arranging symmetrical (e.g., testing whether participants match B to A) or transitive (e.g., after indirect training, testing whether participants match A to B) trials. Prior work suggests that performance in this procedure is mediated by associative processes (see e.g., Hall, 2001; Minster et al., 2011; Pimenta & Tonneau, 2016; Tonneau, 2001), supporting its use as a method for pretraining associations in the current study.

In the present experiment, participants completed a pretraining phase in which they learned to match elements together directly or indirectly. These elements were then compounded together in the standard simultaneous-discrimination procedure used to study stimulus overselectivity. To control for the effects of exposure to the compound-stimulus elements or of pretraining itself, we also included two control groups in which participants matched each element to itself (e.g., A to A) or indirect associations were trained between elements that were not later compounded. In line with comparator theory, we expected overselectivity to be lower for compound stimuli composed of elements that had been associated together directly or indirectly during pretraining, compared with compounds for which no such associations had been trained.

2. Method

All procedures were approved by The University of Auckland Human Participants Ethics Committee (ref. 25132).

2.1. Participants

A total of 462 healthy adults (79 male, 370 female, 9 gender diverse, 4 missing gender data) with a mean age of 19.73 years (SD = 3.76) participated. Participants were students enrolled at a large university in New Zealand. They were recruited via the university's participant pool management system (SONA) system and received course credit for participating. All participants provided informed consent before participating. None of the participants had a formal diagnosis of ASD. All participants completed the Autism Quotient Questionnaire (AQ; Baron-Cohen et al., 2001). AQ scores ranged from 4 to 44 (M = 20.04, SD = 7.41), with 37 participants scoring above 32 (suggestive of clinically significant levels of autistic traits).

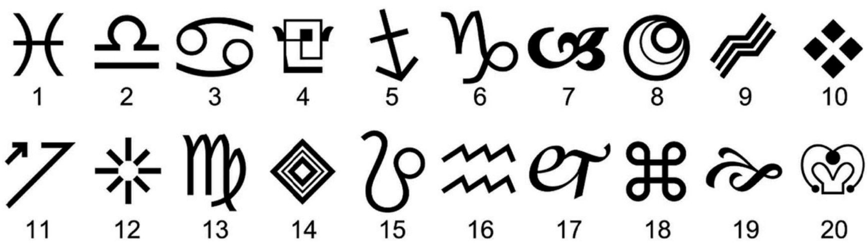

Fig. 1. Abstract symbols used as stimulus elements.

The program running the experiment randomly assigned participants to one of four groups: Group Direct ($N = 113$), Group Indirect ($N = 119$), Group Indirect-Control ($N = 112$), or Group Identity-Control ($N = 118$).

2.2. Materials

The experiment ran on Psytoolkit (Stoet, 2010, 2017). Participants received a link to the experiment, and completed one session remotely on their own device. The experiment was designed to be compatible with a range of devices, including personal computers, laptops, tablets, and smartphones.

Stimulus elements were abstract symbols from the fonts Wingdings, Wingdings 2, Stylebats, and Larasukma. There were 20 symbols in total (see Fig. 1), and the program running the experiment randomly selected 19 of the symbols to serve as stimulus elements A to S for each participant. Hence, the specific symbol corresponding to each element varied between participants.

2.3. Procedure

Experimental sessions were split into two phases. In the pretraining phase, associations between stimulus elements were trained using a matching-to-sample (MTS) procedure. Then, in the overselectivity phase, participants completed a simultaneous-discrimination task involving compound stimuli. The compound stimuli were composed of stimulus elements that had been associated together in the pretraining phase for two groups of participants (Direct and Indirect), whereas such associations were not trained for the two control groups (Indirect Control and Identity Control). Fig. 2 shows the associations that were trained and tested in the pretraining phase for each group, and the stimuli that were used in the overselectivity phase. Before each phase, participants read instructions about the phase and completed a few practice trials to familiarize themselves with the tasks. The instructions and information on practice trials are provided in Appendix A.

2.3.1. Pretraining phase

The aim of this phase was to establish associations between stimulus elements that would later be compounded together. Fig. 3A shows a typical trial, which began with the 500-ms presentation of a fixation cross in the center of the screen. Then, a sample element appeared in the center of the screen, with the prompt "Click the symbol" below the sample. After a response (mouse click or touch) to the sample, three comparison elements appeared in three randomly selected corners of the screen. One comparison matched the sample; choice of the matching comparison resulted in the other comparison stimuli disappearing and the presentation of positive feedback ("Correct!" presented below the sample for 1.5 s) whereas choice of any other comparison was followed by negative feedback ("Wrong!"). If participants did not choose a comparison within 3 s, the words "Choose the symbol that you think matches this one" appeared next to the sample to prompt a response. Trials were followed by a 1-s intertrial interval, during which the screen was blank.

<table>
<tr><th></th><th colspan="2">Phase 1: Pretraining</th><th colspan="2">Phase 2: Overselectivity</th></tr>
<tr><th></th><th>Training trials</th><th>Test trials</th><th>Training trials</th><th>Test trials</th></tr>
<tr><td>Direct</td><td>A → BMN; C → DMN; I → JMN; K → LMN</td><td>B → ACD; D → CAB; J → IKL; L → KIJ</td><td rowspan="4">AB (+) vs CD (-)
EF (+) vs GH (-)</td><td rowspan="4">A vs C
A vs D
B vs C
B vs D
E vs G
E vs H
F vs G
F vs H</td></tr>
<tr><td>Indirect</td><td>A → MNO; B → MNO; C → NMO; D → NMO</td><td>A → BCD; B → ACD; C → DAB; D → CAB</td></tr>
<tr><td>Indirect Control</td><td>P → MNO; Q → MNO; R → NMO; S → NMO</td><td>P → QRS; Q → PRS; R → SPQ; S → RPQ</td></tr>
<tr><td>Identity Control</td><td>A → ANO; B → BNO; C → CMO; D → DMO</td><td>A → BCD; B → ACD; C → DAB; D → CAB</td></tr>
</table>

Fig. 2. *Schematic of the present experiment. Note.* Underlined stimuli in the left panels indicate the comparison that was correct.

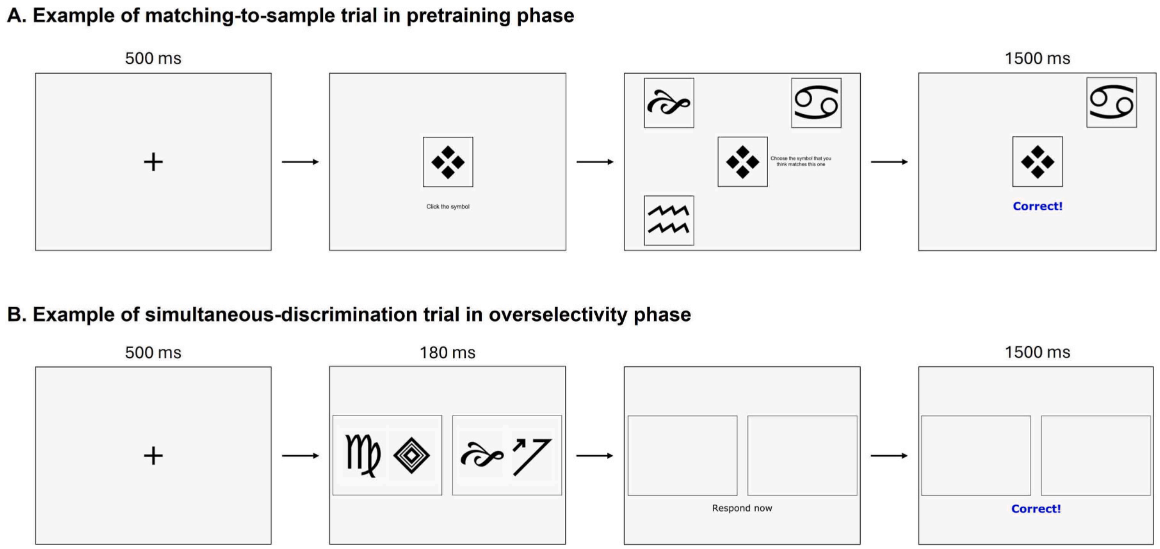

Fig. 3. *Sequence of events in a trial in the pretraining (Panel A, top) and overselectivity (Panel B, bottom) phases. Note.* In the pretraining phase (Panel A), a response to the sample stimulus resulted in the presentation of three comparison stimuli. After 3 s, if no choice was made, the prompt "Choose the symbol that you think matches this one" appeared to the right of the sample stimulus. In the overselectivity phase (Panel B), the stimuli automatically disappeared after 180 ms and then participants were prompted to make a choice. See text for further details.

2.3.1.1. Group Direct. For Group Direct, associations between stimulus elements that would later be presented in compound were trained directly (Fig. 2). Participants learned four sample→comparison relations (A→B, C→D, I→J, and K→L). The comparison stimuli consisted of the correct matching element, plus two randomly selected elements from M, N, and O. Training lasted for a minimum of 72 trials (split evenly between the four trained relations and presented in a random order), and then continued until participants reached 85% correct for all four associations or 120 trials had been completed, whichever occurred first.

To test for the formation of associations between the stimulus elements, we arranged unreinforced trials which tested for the emergence of symmetrical relations between the elements (i.e., B→A, D→C, J→I, and L→K). We expected accuracy in test trials to be high to the extent that pretraining successfully established associations between the elements (see e.g., Fields et al., 1984; Minster et al., 2011; Tonneau, 2001). Participants were instructed to continue choosing the matching stimulus, but that not all trials would result in feedback. Test trials were similar to training trials, except that the comparison stimuli consisted of the elements that had appeared as samples during training. If the sample element was B or D, comparison stimuli were selected from elements A to D (excluding the sample; see Fig. 2), whereas if the sample was J or L, the comparison stimuli were selected from elements I to L. There were 16 test trials (four per relation), which were interspersed randomly among 32 training trials. Thus, there were 48 trials total during testing.

2.3.1.2. Group Indirect. For Group Indirect, associations between stimulus elements were established indirectly via many-to-one training (Fig. 2). Thus, participants learned to match elements A and B to element M, and elements C and D to element N. After training, we tested for emergent symmetric-transitive relations (i.e., A→B, B→A, C→D, and D→C). All other details were the same as Group Direct.

2.3.1.3. Group Indirect-Control. The training and testing procedures for Group Indirect-Control were identical to Group Indirect, except that different sample elements (P to S) were used (Fig. 2). Thus, participants in this group were exposed to the same matching task as Group Indirect, except that the elements differed from those that would appear later in the overselectivity task.

2.3.1.4. Group Identity-Control. The training and testing procedures for Group Identity-Control were identical to other groups, except that participants matched each sample element to itself (Fig. 2). Hence, participants in this group were exposed to the elements that would appear in the overselectivity task, but associations between those elements were not trained. To maintain consistency with the other groups, the same test trials as Group Indirect were arranged in this group.

2.3.2. Overselectivity phase

To investigate whether training associations between stimulus elements in the pretraining phase impacted stimulus overselectivity, we arranged a simultaneous-discrimination task in which participants learned to choose one compound stimulus (the S+) over another compound (S-). This phase was identical for all participant groups (Fig. 2). There were two pairs of compound stimuli: AB (S+) vs. CD (S-), and EF (S+) vs. GH (S-). Thus, for Groups Direct and Indirect, one pair of compound stimuli (AB vs. CD) consisted of elements that had been associated together in pretraining, whereas the other pair (EF vs. GH) consisted of novel elements. For Group Identity-

Control, one pair of compound stimuli (AB vs. CD) consisted of elements that had been used (but not associated together) in pretraining, whereas all compound stimuli were composed of novel elements for Group Indirect-Control.

Fig. 3B shows a typical trial in the overselectivity phase. Each trial began with a 500-ms fixation cross, after which compound S+ and S- stimuli appeared in rectangular boxes on the left and right sides of the screen. The locations of the stimuli were randomized across trials. To induce overselectivity, stimuli were presented rapidly for 180 ms (see Gomes-Ng et al., 2025). Thereafter, the prompt “Respond now” appeared at the bottom of the screen. Participants chose a stimulus by clicking its rectangle. During training, choice of the S+ stimulus was followed by positive feedback, whereas choice of the S- stimulus was followed by negative feedback. Trials were separated by a 500-ms intertrial interval. Training lasted for a minimum of 20 trials (10 per compound-stimulus pair), and then continued until participants chose the correct stimulus in at least 85% of trials for each compound-stimulus pair or for 100 trials maximum, whichever occurred first. Participants then completed a test phase in which they chose between individual S+ and S- elements. There were eight pairs (see Fig. 2), and each pair was presented five times for a total of 40 test trials. Trials were presented in a random order, and no feedback was provided during testing (as in the pretraining phase, participants were informed that feedback would not be provided, but that they should continue to make correct choices).

2.4. Data analysis

2.4.1. Exclusions

In line with previous research, we excluded participants with AQ scores of 32 or greater from analyses because such scores suggest clinically significant symptoms of ASD (see e.g., Kelly et al., 2015; Reed, 2011, 2019; Reed & Gibson, 2005, for further discussion). There were 37 participants excluded based on AQ score, with $N = 14$, 10, 8, and 5 from Groups Direct, Indirect, Indirect-Control, and Identity-Control, respectively.

During the overselectivity phase, participants learned a simultaneous discrimination with compound stimuli. (AB vs. CD, and EF vs. GH). Because we required evidence of control by the compound stimuli in order to assess overselectivity, we also excluded participants who appeared not to learn the discrimination. There were 74 participants who did not reach the performance criterion of 85% correct for both compound-stimulus pairs within 100 training trials. Of these, 33 participants reached 75% correct, suggesting they did learn the discrimination. We thus excluded the other 41 participants’ data from analysis, with $N = 6$, 11, 11, and 13 excluded from Groups Direct, Indirect, Indirect-Control, and Identity-Control, respectively.

In sum, a total of 78 participants’ data were excluded based either on a high AQ score or low accuracy in training trials in the overselectivity place. The final sample size thus consisted of 384 participants, with $N = 93$ in Group Direct, $N = 98$ in Group Indirect, $N = 93$ in Group Indirect-Control, and $N = 100$ in Group Identity-Control.

2.4.2. Pretraining phase

We first examined whether participants learned associations between the stimulus elements. Correct and incorrect responses were separated according to trial type, and we used these to calculate percentage correct in each type of trial. In Group Identity, there was no correct comparison in test trials because participants did not learn associations between the elements (see Fig. 2); hence, to analyze test-trial data for Group Identity, we used the same correct comparison elements as in Group Indirect. We used one-way ANOVAs to compare the number of training trials to reach the criterion of 85% or percentage correct between groups. To assess performance after test trials were introduced (i.e., the last 48 trials of pretraining), we used a repeated-measures ANOVA to compare accuracy in training trials before and after test trials were introduced, and one-sample *t*-tests to test whether percentage correct in test trials was significantly above change.

2.4.3. Overselectivity phase

Correct and incorrect responses were separated according to the compound-stimulus pair (AB vs. CD, or EF vs. GH), and we calculated percentage choice of the S + stimulus in training and testing. We compared the number of training trials and percentage correct during training between groups using a mixed ANOVA with group as a between-subjects factor and stimulus pair as a within-subjects factor.

To analyze levels of overselectivity, we examined the frequency of choice of each S+ element (A, B, E, and F) in test trials. The element of each compound that was selected more frequently was classified as the most-selected (i.e., overselected) element, and the other element was classified as the least-selected (i.e., underselected) element. We then calculated levels of overselectivity by taking the difference in percentage choice between the most- and least-selected elements of each compound.

To determine whether overselectivity levels differed from chance (i.e., from what would be expected if both stimulus elements had the same probability of being chosen in test trials), we conducted an analysis based on the binomial distribution (see Gomes-Ng et al., 2023, 2025; Reynolds & Reed, 2011; Reed, Reynolds, & Fermandel, 2012). To determine expected levels of overselectivity, we first calculated the mean probability, p, of choosing the most- and least-selected elements of each compound during testing for each participant. Then, we calculated the probability of choosing the most-selected element x times in 10 trials and the least-selected element y times in 10 trials $P(X \cap Y)$, where $X \sim Binomial(x_{\in\ [0,\ 10]}, p)$ and $Y \sim Binomial(y_{\in\ [0,\ 10]}, p)$. These probabilities were entered into an 11×11 contingency table, and the contents of this table were multiplied by another 11×11 table containing the absolute $|x - y|$ difference for each combination of x and y. Summing all cells of the resulting table and multiplying by 10 produced the expected difference in percentage choice of the most- and least-selected elements of the compound. We used one-tailed paired-samples *t*-tests to compare these expected overselectivity levels with obtained levels. Finally, we used a mixed ANOVA to compare overselectivity levels between compounds (within-subjects factor) and groups (between-subjects factor).

2.4.4. Statistical analyses

We used Bayesian hypothesis tests for all statistical analyses. Bayesian tests quantify the strength of the evidence for the null or alternative hypothesis with a Bayes factor (BF_{10}), rather than just providing a *p* value. Specifically, the Bayes factor reflects the likelihood of the alternative hypothesis (e.g., differences between compound-stimulus pairs or groups) relative to the null hypothesis given the obtained data (Wagenmakers et al., 2018; Wagenmakers et al., 2018). We interpreted the Bayes factor using Lee and Wagenmakers' (2013) classification, where a BF_{10} value of 1 indicates no evidence for either hypothesis, and values greater than 1 indicate support for the alternative hypothesis, with larger values reflecting stronger support. Likewise, a BF_{10} value less than 1 indicates support for the null hypothesis, with smaller values indicating stronger support for the null hypothesis.

3. Results

3.1. Did participants learn associations between the stimulus elements during pretraining?

The purpose of the pretraining phase was to establish associations between stimulus elements that would later be compounded together in the overselectivity phase. The mean number of training trials to reach the performance criterion of 85% correct was 88.36 (*SEM* = 2.00) for Group Direct, 103.98 (*SEM* = 1.94) for Group Indirect, 101.25 (*SEM* = 2.10) for Group Indirect-Control, and 72.18 (*SEM* = 0.18) for Group Identity-Control. Hence, participants who matched each element to itself required the least number of training trials, whereas those who underwent many-to-one training required the most trials. There was extremely strong support for this between-groups difference in the number of training trials (Bayesian one-way ANOVA: $BF_{10} = 9.94 \times 10^{33}$, error % < 0.001).

Fig. 4 shows mean percentage correct in each trial type in the last 48 trials of training (i.e., before test trials were introduced; unshaded bars) and after test trials were introduced (shaded bars). Focusing first on the trained relations, mean percentage correct was close to 100% for all training trial types and in all groups. There were small decreases in percentage correct in training trials after test trials were introduced (see Fig. 2), and this was slightly more evident in Groups Indirect and Indirect-Control. A Bayesian mixed ANOVA indicated that the model with the strongest support contained both the effect of phase (before or after test trials) and group (all other models $BF_{10} < 0.3$). Nevertheless, the trained relations were clearly maintained even after test trials were introduced, as mean percentage correct remained above 95% (Fig. 2). Thus, introducing test trials had only a small effect, if any, on performance in training trials.

To determine whether associations between elements A, B, C, and D (or P, Q, R, and S in Group Indirect-Control) had been established, we tested for the emergence of symmetrical and/or transitive relations (see Fig. 2). If such emergence occurred, accuracy should be high for all four test-trial types in each group. Fig. 4 shows that mean percentage correct in test trials was high and above

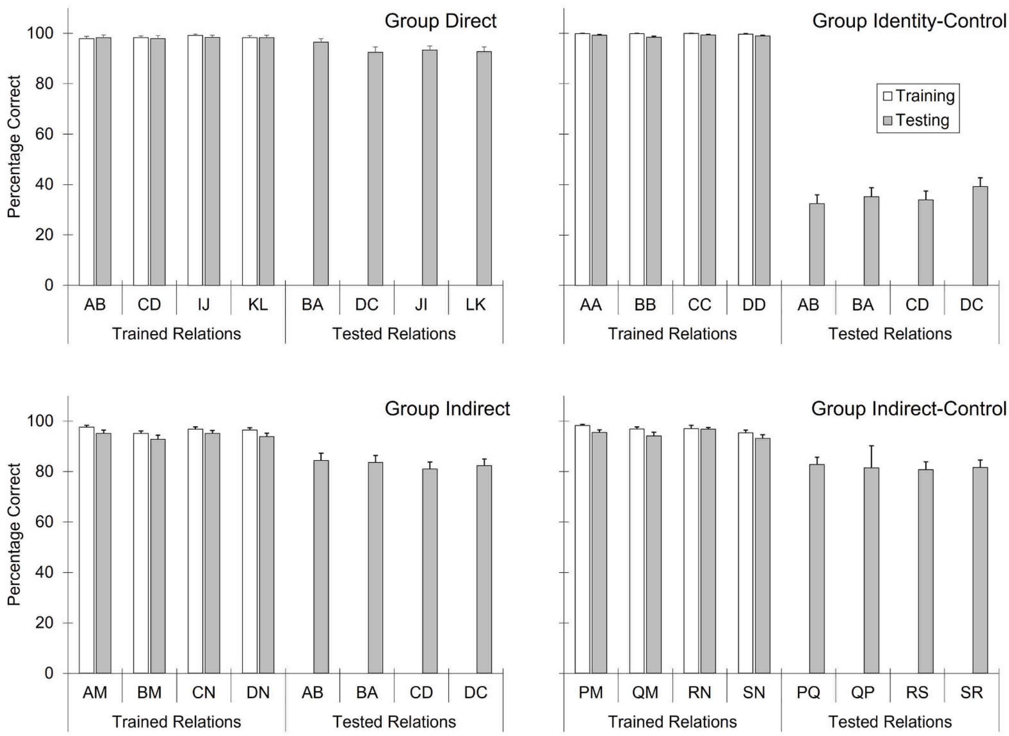

Fig. 4. *Mean percentage correct in the pretraining phase. Note.* Data are averaged across participants in each group. Unshaded bars show data from the last 48 trials of training, and shaded bars show data from all 48 trials in testing. Error bars show the SEM.

chance for participants for whom associations between elements were trained directly or indirectly (Groups Direct, Indirect, and Indirect-Control; Bayesian one-sample *t*-tests: all BF_{10} values $> 10^{25}$). However, only 63 participants (67.7%) in Group Direct, 50 participants (51.0%) in Group Indirect, and 52 participants (55.9%) in Group Indirect-Control reached 85% correct in all four test-trial types. Thus, although overall performance in test trials was high (Fig. 4), only about half of participants demonstrated the emergence of all tested relations after direct or indirect training. Unsurprisingly, when associations between elements were not trained (Group Identity-Control), choice in test trials did not differ from chance (all BF_{10} values < 0.4).

3.2. Did establishing associations between stimulus elements reduce overselectivity?

Our primary aim was to investigate whether establishing associations between elements A, B, C, and D in pretraining influenced levels of overselectivity in a subsequent simultaneous-discrimination task involving those elements (see Fig. 2). In the overselectivity phase, participants learned to choose a compound S+ stimulus (AB or EF) over a compound S- stimulus (CD or GH). Table 1 shows the mean number of trials and percentage correct during discrimination training for each compound-stimulus pair and participant group. For training trials to criterion, a Bayesian mixed ANOVA provided strong evidence in favor of the null model over models including stimulus pair, group, or the pair x group interaction (all BF_{10} values < 0.4). Hence, prior exposure to elements A, B, C, and D in the pretraining phase did not influence the speed of acquisition in the overselectivity phase. The same pattern was observed for percentage correct, with the strongest evidence in favor of the null model (all BF_{10} values < 0.4). Hence, training performance was comparable across compound-stimulus pairs and participant groups.

The left panel of Fig. 5 shows mean percentage choice of the most- and least-selected elements of each compound stimulus in test trials, and the right panel shows mean overselectivity levels (i.e., the difference in percentage choice between the most- and least-selected elements of each compound). To determine whether levels of overselectivity differed from levels expected based on chance alone, we compared obtained and expected levels using Bayesian one-tailed paired-samples *t*-tests. Table 2 shows mean obtained and expected levels in each group, and the results of the *t*-tests. Obtained overselectivity levels were larger than expected levels for both compounds in all groups, and there was strong support for this difference. Thus, our procedure successfully induced overselectivity.

We hypothesized that in Groups Direct and Indirect, levels of overselectivity would be lower for the compound composed of elements that had been associated together during pretraining (Compound AB) compared with the compound composed of novel elements (Compound EF). Differences in obtained overselectivity levels between compounds in these groups did appear to trend in the predicted direction (see right panel of Fig. 5). However, the same difference was also apparent in Group Identity-Control, even though associations between elements A and B had not been trained during pretraining. Moreover, a Bayesian mixed ANOVA with compound (AB or EF) as a within-subjects factor and group as a between-subjects factor provided strong support for the null model over all alternative models (all BF_{10} values < 0.3). To determine whether the lack of systematic differences between compounds was related to differences in training performance, we also ran this ANOVA with data from all participants except those with AQ scores above 31,[3] and with percentage correct during the pretraining phase and during training trials in the overselectivity phase as covariates. This did not change the results, with strong support for the null model over all other models (all BF_{10} values < 0.5), hence, differences in performance during pretraining or during training trials in the overselectivity phase did not influence overselectivity levels.

During the pretraining phase, only about half of participants demonstrated the emergence of tested relations in all four types of test trials. This suggests that pretraining established strong associations between the stimulus elements for these participants, whereas such associations were either not established or were much weaker for the remaining participants. We therefore compared overselectivity levels between participants who clearly learned the stimulus associations (i.e., had high accuracy across all four test trials during pretraining) and those who did not. However, strong support for the null model remained even when pretraining association formation (strong vs. not strong) was included in the Bayesian mixed ANOVA (all other models $BF_{10} < 0.9$). Therefore, despite suggestive within-group patterns (particularly in Group Direct; see right panel of Fig. 5), there was no reliable evidence that direct or indirect training of element associations influenced subsequent levels of overselectivity, not even for participants who clearly learned strong associations between elements during pretraining.

4. Discussion

Previous research suggests that within-compound associations play an important role in stimulus overselectivity, with stronger associations resulting in lower levels of overselectivity (e.g., Reed, 2011; Reed & Quigley, 2019; Reynolds & Reed, 2011, 2018). The present experiment investigated how separately establishing associations between stimulus elements influences overselectivity when those elements are compounded together in a subsequent simultaneous-discrimination task. During pretraining, associations between relevant stimulus elements were trained directly for one group of participants (Group Direct), indirectly via many-to-one training for another group (Group Indirect), and not at all for two control groups (Groups Indirect-Control and Identity-Control). These control groups were designed to control for the effects of pretraining in general (Group Indirect-Control) and for the effects of exposure to the stimulus elements (Group Identity-Control). After pretraining, all participants completed a simultaneous-discrimination task in which rapidly presented compound stimuli were composed of pretrained or novel elements. This procedure successfully induced

[3] There were 431 participants included in this analysis ($N = 99$ in Group Direct, 112 in Group Indirect, 107 in Group Indirect-Control, and 113 in Group Identity-Control).

Table 1
Mean (SEM) number of training trials and percentage correct in the overselectivity phase.

Group	N	AB vs. CD		EF vs. GH	
		Trials	%	Trials	%
Direct	93	23.77 (1.46)	90.84 (0.65)	23.51 (1.44)	89.98 (0.51)
Indirect	98	21.20 (1.29)	90.71 (0.59)	21.04 (1.27)	90.88 (0.56)
Indirect-Control	93	22.10 (1.42)	90.30 (0.64)	21.68 (1.40)	92.05 (0.62)
Identity-Control	100	22.78 (1.31)	90.28 (0.59)	22.80 (1.28)	90.23 (0.55)

Note. Participants with AQ scores above 31 or who did not reach the training criterion were excluded.

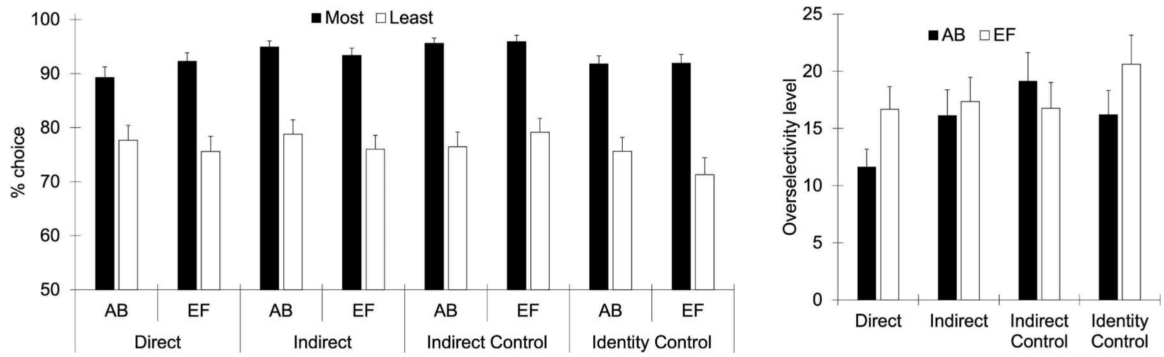

Fig. 5. *Mean percentage choice of each element (left panel) and overselectivity levels (right panel). Note.* Data are averaged across participants in each group. 'Most' and 'Least' refer to the most-selected and least-selected element of each compound. Error bars represent the SEM.

Table 2
Expected and obtained levels of overselectivity.

Group	Compound AB			Compound EF		
	Expected (SEM)	Obtained (SEM)	BF_{10}	Expected (SEM)	Obtained (SEM)	BF_{10}
Direct	7.92 (0.69)	11.61 (1.58)	15.19	8.64 (0.66)	16.67 (2.00)	15254.22
Indirect	7.35 (0.71)	16.12 (2.25)	11286.81	6.40 (0.65)	20.98 (2.12)	9718.89
Indirect-Control	8.25 (0.71)	19.14 (2.50)	48070.64	7.56 (0.68)	16.77 (2.24)	24500.11
Identity-Control	8.68 (0.70)	16.20 (2.13)	1008.24	8.80 (0.70)	20.60 (2.57)	134844.85

Note. BF_{10} shows the Bayes Factor for Bayesian one-tailed paired-samples *t*-tests comparing expected and obtained overselectivity levels. Expected values show levels of overselectivity that would be obtained due to chance alone. All error percentages were less than 0.0001.

overselectivity in all groups (Fig. 5), adding to the evidence showing that overselectivity occurs in healthy adults under conditions that make discrimination learning more difficult (see also Broomfield et al., 2010; Gomes-Ng et al., 2023, 2025; Reed et al., 2012; Reynolds & Reed, 2018). However, there was little difference in overselectivity between groups. Thus, contrary to our expectations, pretraining stimulus associations did not attenuate stimulus overselectivity in the present experiment.

To our knowledge, the present experiment is the first to pretrain associations between stimulus elements in a matching-to-sample task and then compound those elements in a discrimination task to assess stimulus overselectivity. Given the limited amount of work in this area, the possible explanations for our null result are unclear. One possibility is associations established in a matching-to-sample task may not generalize to compound-stimulus elements in simultaneous-discrimination task due to structural differences between the tasks (see Figs. 1 and 2; see e.g., Archer et al., 1986; Blaisdell et al., 1998; Gray et al., 2001; Lubow et al., 1976; Quintero et al., 2011; Tsakanikos & Reed, 2004 for findings showing that contextual changes attenuate the effects of stimulus preexposure). Additionally, while stimulus elements were spatially separated (and in different locations) during pretraining, they were presented adjacently in the same compound configuration during training in the overselectivity phase (see Fig. 3). It is possible that stimuli were processed differently in these phases – elementally (i.e., as individual elements) during pretraining, but configurally (i.e., as a whole compound) during the overselectivity phase. Indeed, such processing can vary flexibly depending on task demands, prior experience, and stimulus characteristics (see Melchers et al., 2008, for a review). Thus, the different stimulus configurations may have weakened generalization of any pretraining effects to the overselectivity phase. Further, some evidence suggests that pretraining with elemental stimuli has stronger effects on later discrimination learning if pretraining performance is higher and when tasks are similar in difficulty (e.g., Alcalá et al., 2023; Mehta & Williams, 2002; Melchers et al., 2005). In the present experiment, pretraining involved learning several relationships between individual elements, whereas the overselectivity phase only involved learning to choose one correct S+ from the same pair of compound stimuli. Hence, compared with the overselectivity phase, our participants may have found the pretraining phase more difficult (indeed, performance in test trials suggests that about half of participants did not acquire strong associations between elements), thereby weakening the effects of pretraining on stimulus overselectivity. Overall, this line of reasoning suggests that future work should minimize differences in task structure and stimulus configuration between the pretraining and overselectivity phases to increase the likelihood that pretraining effects generalize to the overselectivity task.

Alternatively, the effects of within-compound associations may be better examined using a ‘revaluation’ procedure in which choice of the overselected element is extinguished (e.g., Broomfield et al., 2010; Gomes-Ng et al., 2023; Reed et al., 2009). Some researchers suggest that within-compound associations play a stronger role in retrospective revaluation than they do in conventional stimulus competition (i.e., overshadowing or overselectivity; see Amundson et al., 2008, for a brief discussion). That is, stronger within-compound associations may reduce control by the underselected element after extinction of the overselected element (mediated extinction) whereas weaker associations may increase control by the underselected element (retrospective revaluation; see Gomes-Ng et al., 2023; Liljeholm & Balleine, 2009; Reynolds & Reed, 2018; Shevill & Hall, 2004; Sissons et al., 2009). Therefore, including a revaluation procedure in future replications of our experiment may provide clearer insight into the effects of pretraining on within-compound associations.

Our study shares similarities with Amundson et al. (2008), who established inhibitory associations between two stimulus elements A and X via pairing with a common element C in an overshadowing procedure. However, unlike the present results, Amundson et al. found that establishing such associations reduced overshadowing when A and X were later compounded together. The reasons for this difference in results are unclear. One important difference between overselectivity and overshadowing is that the former is assessed by comparing the strength of control by each compound-stimulus element in a choice procedure (see Fig. 2), whereas in an overshadowing procedure, responding to one element (e.g., X) after compound training (e.g., AX) is compared with responding to that element after single-element training (e.g., X alone). Hence, although similar mechanisms may underlie both phenomena (see e.g., Reed & Quigley, 2019; Reynolds & Reed, 2018), differences between the overselectivity and overshadowing procedures make it difficult to compare results directly. Because Amundson et al. did not report the degree of control by both compound-stimulus elements, it is unclear whether A and X exerted more equal control (i.e., no overshadowing) after pretraining. Furthermore, inhibitory and excitatory associations differ because in the former one element predicts the absence of the other (e.g., A → not X) but in the latter one element predicts the presence of the other (e.g., A → X, as in the present experiment; see Fig. 1). As a result, the degree of competition between two elements may be weaker after inhibitory training – hence reducing overshadowing – compared with excitatory training. To be sure, a future study could replicate Amundson et al.'s study but establish an excitatory association during pretraining, or replicate our experiment and establish an inhibitory-like association (e.g., if element X consistently appears as an incorrect comparison after sample-stimulus A, then an inhibitory-like relationship between A and X may form).

The present findings are informative with respect to a suggestion by Gomes-Ng et al. (2023) that similar mechanisms underlie stimulus overselectivity and stimulus equivalence. This suggestion was based on the finding that initial levels of overselectivity modulated the effects of revaluation on stimulus control. Specifically, for participants with low overselectivity, extinguishing the overselected element of one compound reduced responding to the underselected element of that compound and to both elements of a control compound. In contrast, for participants with high overselectivity, control by the underselected element of the revalued compound increased and no systematic changes were observed for the control compound. Gomes-Ng et al. suggested that for participants with low overselectivity, strong associations formed between the elements within each compound stimulus, as well as between the revalued and control compounds due to their common function as S+ stimuli. According to this account, extinguishing one element also reduced control by the other, functionally equivalent, elements. This implies that establishing associations between stimulus elements in an equivalence-like procedure should attenuate overselectivity when those elements are compounded together. Our null results appear not to support this implication, and hence suggest that the mechanisms underlying overselectivity and equivalence are at least partially distinct.

In summary, our findings provide little evidence that establishing relationships between stimulus elements in a matching-to-sample procedure via direct or indirect pairing reduces stimulus overselectivity. Nevertheless, it is worth noting that differences in overselectivity between the compound composed of pretrained elements and the compound composed of novel elements did trend in the expected direction in Group Direct, and to a lesser extent in Group Indirect (right panel of Fig. 5). This highlights the need for further research that examines how learning histories influence complex stimulus control. Our discussion raises several promising avenues for such future work. First, as noted earlier, arranging a revaluation procedure would provide further clarification on whether pretraining systematically influences within-compound associations. Second, future work could examine whether generalization decrement processes influence the extent to which associations established in one task transfer to other tasks, by comparing overselectivity when pretraining and overselectivity tasks are more structurally similar or dissimilar. Finally, studies that directly compare overselectivity and overshadowing will be important for clarifying the extent to which these phenomena reflect common stimulus-competition mechanisms (as per comparator theory). Such future investigations will help to advance our understanding of how prior experience with individual stimuli modulates control by those stimuli when they are later combined together, and the boundary conditions under which pretraining histories do, or do not, modulate stimulus overselectivity.

CRediT authorship contribution statement

Stephanie Gomes-Ng: Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Douglas Elliffe:** Writing – review & editing, Supervision, Resources, Methodology. **Sarah Cowie:** Writing – review & editing, Supervision, Resources.

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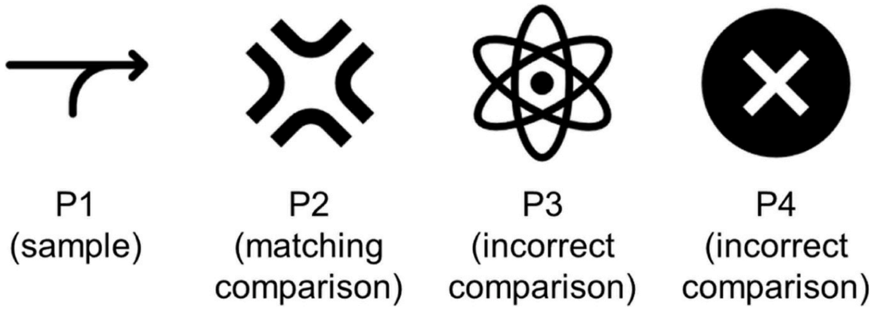
Appendix A

Task instructions and practice trials

Pretraining Phase

In this phase, participants completed a matching-to-sample task in which they learned to match stimulus elements together. Before beginning the task, a’’ participants read the following instructions: “*In this task, you will play a matching game. You will match a symbol in the middle of the screen to one of three symbols in the corners of the screen. Use your mouse to click the symbols (or your finger, if on a touchscreen device). Sometimes, the program will tell you if you matched correctly. Use this feedback to learn about which symbols match each other! Your goal is to make correct responses. The more correct responses you make, the shorter the experiment will be.*” (The latter instruction reflected the performance criterion, and also helped motivate participants to respond correctly.)

Participants completed six practice trials. Practice trials were identical to experimental trials (described in the Procedure, 2.3.1), except that stimulus elements P1 to P4 were used (see Appendix Figure A1). Element P1 was always the sample element, and the other three elements were always the comparison elements. Element P2 matched the sample in practice trials. After completing the practice trials, the experiment proper began.



Appendix Figure A1. Elements used in practice trials during pretraining

Overselectivity Phase

In the overselectivity phase, participants completed a simultaneous discrimination task in which they learned to choose one compound stimulus (the S+) over another compound (the S-). At the start of the phase, participants read the following instructions: *“In this next task, you will make choices between different symbols. The symbols will appear in rectangles on the left and right hand sides of the screen. Choose by clicking with your mouse or touching with your finger. Sometimes, the program will tell you if you chose correctly. At other times, there will be no feedback. Your goal is to make correct choices. The more correct choices you make, the shorter the experiment will be.”* After reading these instructions, participants completed eight practice trials in which they chose between an apple (the S+) and balloon (the S-). Practice trials were identical to experimental trials (see Procedure, 2.3.2).

Data availability

Data will be made available on request.

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