Differential Crel and Cfunc Acquisition through Stimulus Pairing

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Abstract

Some learning psychologists refer to relational cues (Crels) and functional cues (Cfuncs) in their analyses of verbal behavior. However, past research about Crels and Cfuncs is limited in two ways. First, there has been relatively little research into how Crels and Cfunc functions can be acquired, and whether such acquisition is similar to the acquisition of other stimulus functions (e.g., SDs). Secondly, research into Crel and Cfunc functions has typically investigated each separately (i.e., either examining Crels or Cfuncs), although a better approximate to real-life learning would examine their simultaneous acquisition. We report studies that examined whether Crels and Cfuncs can be learned simultaneously using a common learning procedure (i.e., stimulus pairing). Experiment 1 examined the transfer of Crel functions for sameness and difference relations and the transfer of Cfunc functions for color and shape to novel stimuli. Experiment 2 examined the transfer of comparative Crel functions (bigger and smaller) and Cfunc functions for value and size. In Experiment 2 we also investigated whether the newly learned functions of the novel stimuli would influence responding to stimuli that were not presented in the learning phase. Our results suggest that Crels and Cfuncs can indeed be acquired via stimulus pairing and can affect also responding to stimuli not used during acquisition.

Keywords: relational contextual control, transformation of function, stimulus pairing, relational frame theory

Every day we make choices that we hardly think about. Suppose that you have to leave for work and that you have the choice to either take the car or the bike. There can be different reasons behind the choice you make. For example, you can make your decision based on environmental friendliness. When you opt for the most environmentally friendly alternative, your preference will most likely be for a bicycle. Of course, there are many other possible reasons that could play a role in making your choice. If speed is an important factor, for example, you may end up taking the car. This example makes clear that behavioral choices are often made based on a relation between objects: you compare the environmental friendliness or speed of one means of transport (car) with another (bicycle). Behavior that we adopt based on a relation between stimuli or events can be referred to as relational behavior (De Houwer & Hughes, 2020). Importantly, stimuli can be related along a variety of dimensions, such as a comparison of speed or of environmental friendliness. In different contexts, different dimensions can be cued as being relevant. Such cues are known as contextual cues, and they are central to the expression of relational behavior. Returning to the previous example, people very often take the weather into account when choosing between cycling and driving. Rainy weather tends to make us base our choice on speed whereas we are more likely to base our choice on environmental friendliness when the weather is clear and sunny. In this case, rainy weather and nice weather function as contextual cues that determine the dimension of comparison (e.g., environmental friendliness or speed) on which we base our choice of transport mode.

In spite of the clear dependence of relational behavior on these *relational contextual cues*, very little research has been conducted on how stimuli come to function in this manner. This is in stark contrast to the wealth of research which has been conducted on the acquisition of nonrelational contextual cues, that is cues that signal nonrelational behavior. These nonrelational contextual cues are typically referred to as discriminative stimuli (i.e., SDs). In the following section, we briefly review research which has investigated the acquisition of SDs through various learning procedures. After this, we detail the few studies which have similarly investigated the acquisition of relational contextual cues through these same learning procedures. Finally, we highlight features of these studies which have been lacking and introduce the current experiments.

Acquisition of SDs

Discriminative control is considered a central part of operant behavior (Skinner, 1953). The establishment of discriminative control and the generation of SDs has been of considerable research interest (Dinsmoor, 1995). The acquisition and change of SD functions has been studied extensively within the context of operant conditioning procedures such as discrimination training (Skinner, 1938; Dinsmoor, 1995; Nakagawa, 1999; see Schlinger & Blakely, 1994, for a review). Researchers have also examined the counterconditioning of SDs (Staddon & Frank, 1974), the impact of the statistical contingency between response and outcome on SD acquisition (Herrnstein, 1970; Nevin, 1974) and higher-order control of SDs (Sidman, 1986; see also Finn et al., 2021).

Aside from discrimination training procedures, another effective method for establishing SDs has been the use of stimulus pairing. This learning procedure involves the repeated pairing of a novel stimulus with another stimulus, such that the novel stimulus eventually acquires the function(s) of the other stimulus. Stimulus pairing has proven to be effective in establishing many different functions such as conditioned reinforcers (e.g. Vandbakk et al., 2019), as well as SDs (e.g., Tonneau & González, 2004; Fields, 2018). To summarize, discriminative stimuli have been studied with a primary focus on how SD functions can be established, maintained, and changed. Importantly for the current article, stimulus pairing has proven to be an effective method for establishing SD functions for novel stimuli. In the next section, we will examine the definition of relational contextual cues, and highlight the comparably limited attention that has been paid to their acquisition compared to the acquisition of SDs.

Relational Contextual Cues

In general, researchers distinguish two types of relational contextual cues: Crels and Cfuncs (Hughes & Barnes-Holmes, 2016). Crels indicate how stimuli are related. For instance, the words SAME and DIFFERENT specify two different ways stimuli may be related. In contrast, Cfuncs determine which stimulus features or functions participate in a relational response. For instance, the words COLOR and SHAPE specify different dimensions along which stimuli may be related. Given that most stimuli in the natural environment have multiple features or functions (e.g., color, shape, frequency etc.) and may be related in multiple ways (e.g., same as, more than, opposite to etc.) Crels and Cfuncs provide essential contextual control over relational behavior. If individuals are provided with a Cfunc in the absence of a Crel, then it remains unclear how to relate stimuli based on that Cfunc. Likewise, if individuals are provided with Crel information but not Cfunc information, then it is unclear by which properties stimuli can be related. Parenthetically, in both foregoing examples relational responses may of course still be emitted, but this relational activity will be less readily predictable as it is not controlled and shaped by its immediate context. As such, the interaction of Crel and Cfunc functions is central to the control of relational behavior, and thus much of human activity (Hayes et al., 2001). Despite this, most existing research on the establishment of relational contextual cues has examined Crels and Cfuncs separately (e.g., McLoughlin & Stewart, 2017; Perez et al., 2017; Stewart et al. 2013; Finn & De Houwer, 2021), rather than manipulating the two simultaneously. We will return to a critique of this practice in a later section; however, for now we separately review the research that has been conducted on the learning and acquisition of Crels and Cfuncs.

Acquisition of Crels

In past research, the training and learning of Crel functions has been done almost exclusively using a single type of learning procedure: the matching-to-sample task (MTS). One such example is a study by Roche and Barnes (1997). In a MTS procedure participants were reinforced for selecting comparison stimuli that were physically identical to the sample stimulus (e.g., selecting a long line when the sample was a long line) in the presence of one cue (e.g., !!!!!!), and were reinforced for choosing comparison stimuli that were physically distinct from sample stimuli (e.g., selecting a long line when the sample was a short line) in the presence of the other cue (%%%%%%). This history of reinforcement was used to ensure that arbitrary symbols such as !!!!!! and %%%%%% acquired the function of SAME and OPPOSITE respectively. As a result of this procedure, participants learned that these cues have a Crel function: they are relational contextual cues in which one cue indicates that one should base one's behavior on a sameness relation whereas the other cue signal that an opposite relation should control behavior.

Importantly, relational contextual control does not only involve relations of sameness and difference. Roche and Dymond (2008) established a Crel function using MTS in two arbitrary contextual cues, which signaled to align behavior with a comparative relation. Here, one cue stood for MORE THAN and the other for LESS THAN. Sample stimuli consisted of images of footballs, and the three comparison stimuli presented were three images of three footballs that were either smaller, the same size or larger than the footballs in the sample stimulus image. In the presence of the Crel for MORE THAN, the choice for the larger-sized football was reinforced, whereas in the presence of the Crel for LESS THAN, the choice for the smaller-sized football was reinforced. The participants learned the relational cues successfully, demonstrating that Crel functions can be acquired via MTS.

In the studies just mentioned and almost all other previous studies, establishing the Crel function was a preliminary step to then investigating the impact of these Crel stimuli on behavior (e.g., Dymond et al, 2007; Roche et al., 2000; Whelan & Barnes-Holmes, 2004). Specifically, these earlier studies used Crels as a means to produce derived transformations of other functions and did not examine the transformation of Crel functions themselves, that is, whether the existing Crel function of one stimulus can influence the Crel functions of other novel stimuli. Instead, these earlier studies focused on establishing novel Crel functions through multiple-exemplar training.

To date, there exists only a small number of articles that focus on the transformation of Crel functions. McLoughlin and Stewart (2017) and Perez et al. (2017) are among the few that have investigated this. McLoughlin and Stewart (2017) used a Relational Evaluation Procedure (REP) of 10 stages to establish the Crel functions SAME, DIFFERENT, OPPOSITE in arbitrary stimuli. Three of the four participants completed this procedure successfully and learned to respond correctly for non-arbitrary as well as arbitrary relations. The second experiment showed the transformation of these relational functions by building on the complex relational network that was established in Experiment 1. In the first five stages novel stimuli acquired the Crel functions of SAME and OPPOSITE through transformation of function via same and opposite relations. The next three stages also aimed to establish Crel functions of SAME and OPPOSITE in other new arbitrary stimuli through transformation of function via same and opposite relations, but now in the context of the relating of the relational networks. All three of the participants successfully completed the protocol.

Perez et al. (2017) demonstrated the transformation of Crel functions through indirect (equivalence) relations. First, as in previous experiments, Crel functions were established in two neutral symbols via a non-arbitrary MTS task. Each trial consisted of the presentation of one of the two neutral symbols, followed by the presentation of a sample stimulus and three comparison stimuli that were related along a physical dimension (e.g., length of horizontal line). Based on feedback, the original neutral stimuli acquired the function of a relational cue for sameness or opposition (Crel SAME/Crel OPPOSITE). Participants also responded correctly with new sample and comparison stimuli, that is, the Crel function also influenced responding to stimuli other than those used during acquisition. In a second phase, these contextual cues, which controlled initial relational behavior based on physical characteristics, were used to learn arbitrary relations between nonsense words. This was again accomplished via an MTS task in which first the learned cue for sameness or opposition appeared, followed by the presentation of the sample and three comparison stimuli, specifically different six-letter nonsense words that belong to different sets. Four different relations were learned, for example BETRCT *same as* CIPHER, BETRCT *opposite to* LEWOLY, BETRCT *same as* MURBEN, BETRCT *opposite to* RIGUND. After this training, it was tested whether new relations were derived, such as CIPHER *same as* MURBEN or RIGUND *opposite to* MURBEN.

In a third phase, the Crels (SAME/OPPOSITE) themselves were put into an equivalence relation with new stimuli. The fourth and final phase was a test phase consisting of a repetition of the test parts of the first and second phases, with the difference that the original Crel stimuli were replaced by the equivalent stimuli. Perez et al. (2017) found that relational responding was maintained after this replacement. This indicated that the new symbols had acquired the Crel function via the equivalence relations. Thus, there is evidence for the transformation of Crel functions, more specifically for the relations SAME and OPPOSITE. In other tasks, Perez et al. (2017) also found evidence for the transfer of the Crel function for comparative relations (MORE THAN and LESS THAN). They found such transfer even though there was no direct relationship between stimuli (i.e., never occurring together in time and space).

Acquisition of Cfuncs

Little research exists on the transformation of Cfunc functions. Of the few studies investigating Cfunc control, most have used MTS procedures in a similar manner to those investigating Crel control. For example, in the study of Stewart et al. (2013), participants were initially taught different Crel stimuli (abstract forms) via a non-arbitrary MTS task, more specifically for the relations of sameness, difference, and opposition. In a subsequent phase, contextual control for relational behavior was refined by using stimuli that operated as Cfuncs in addition to Crels. Each of the sample and comparison stimuli presented in this study involved up to four instances of one of four kinds of shape that contained between one and four dots which could take up to four different sizes. Thus, depending on the functional cues, the relations of sameness, opposition and difference were applied to different stimulus properties such as the number and kind of shape as well as the number and size of dots they contained. For example, in the presence of a Crel for sameness and a Cfunc for number of dots, participants were rewarded for choosing a comparison stimulus that consisted of the same number of dots as the sample stimulus, regardless of the size of the dots. However, in the presence of a Crel for sameness and a Cfunc for size, participants were rewarded to choose a comparison stimulus with dots of the same size, regardless of the number of dots. An aspect of this study that is of direct relevance to the current research is that, once their function was well established, these Cfuncs were then each put into equivalence relations with novel arbitrary stimuli via an MTS task. A subsequent test phase showed that these new stimuli had also acquired a Cfunc function, even when the stimuli had never been presented together.

Another study on Cfunc control was recently conducted by Finn and De Houwer (2021). This study was the first that looked at the selective action of Cfunc control. The general procedure consisted of several stages that aimed to establish arbitrary symbols as Crels for sameness and difference relations via MTS and establish arbitrary symbols as Cfuncs for the stimulus properties of speed and direction via a car race paradigm. As part of the car race paradigm, participants could observe the performance of a sample racecar (i.e., whether it moved quickly or slowly and whether it moved toward or away from the finish line). Crel and Cfunc stimuli provided information about how the speed and direction of other race cars compared to that of sample racecar, more specifically, whether each racecar moved in the same or different direction and with the same or different speed than the sample racecar. The Cfuncs in this study served to select which stimulus properties (i.e., speed and direction) transformed via which kind of relation (i.e., same or opposite). For example, it was possible to specify that a racecar went in the same (Crel) direction (Cfunc) but at a different (Crel) speed (Cfunc) to the sample racecar, thus generating properties for that racecar in that trial. By relying on the feedback provided, the participants learned the functions of the Cfunc stimuli and hence to choose which of the non-sample racecars would win the race that followed. Four experiments with several procedural variations indicated that the establishment of selective action of Cfunc control was obtained by a subset of participants. That is, for these participants Cfuncs controlled the observed transformations by selecting which stimulus functions transformed via which stimulus relations.

Limitations of previous research

Although there is some research on Crels and Cfuncs, it is still in its infancy. First, as stated previously, most of the studies used one type of learning procedure, namely MTS. Second, work on Cfuncs is scarce, with most work on contextual control of relational responding being focused on Crel properties. Third, there is little work on the acquisition of Crels and Cfuncs *simultaneously*. This is problematic, given that Crels and Cfuncs are inherently related (i.e., a function cannot be related unless a dimension is specified, and a dimension cannot be used to relate unless the function to-be-related is specified). Additionally, the acquisition of these functions in everyday learning likely occurs simultaneously due to their interconnectedness. As such, learning observed in previous work is likely different from everyday learning of these cues. An investigation of simultaneous transfer would therefore be closer to the learning we are interested in. Furthermore, there are always multiple relationships between stimuli and these stimuli can also possess multiple functions. Thus, the absence of multiple contextual control in most of the studies is a shortcoming in a similar manner as the absence of simultaneous Crel and Cfunc acquisition.

Current Research

On the basis of the limitations discussed above, as well as the demonstrable importance of Crels and Cfuncs in relational behavior, we investigated whether Crel and Cfunc functions can be (i) transferred via stimulus pairings, while (ii) presenting Crels and Cfuncs simultaneously. We investigated this across two experiments, each consisting of three phases. As formerly noted, previous studies on the transfer of Crel and Cfunc functions focused on transfer of functions via equivalence relations that were brought about by MTS tasks. Our research will also first use an MTS task, but only to reinforce relational responses controlled by contextual stimuli that are presumed to already exert a Crel or Cfunc function in daily life. However, the transfer itself of both functions to new symbols will be achieved via stimulus pairing. Given the effectiveness of pairing in establishing SD functions, we expected that pairing would also be effective in establishing Crel and Cfunc control.

In Experiment 1, we investigated the simultaneous transfer of the Crel functions SAME and DIFFERENT and the Cfunc functions COLOR and SHAPE. Participants only had to base their behavior on the physical characteristics of the stimuli, so solely non-arbitrary relations were important. Experiment 2 was used as a test of generalization of the results of Experiment 1, through the transformation of other Crel (BIGGER/SMALLER) and Cfunc (VALUE/SIZE) functions. In contrast to Experiment 1, both non-arbitrary and arbitrary features of the stimuli had to be considered by the participants. Additionally, in Experiment 2 we examined whether these newly acquired Crel and Cfunc functions subsequently served to control relational responding towards new stimuli, thus assessing the impact of these Crel and Cfunc functions beyond the trained exemplars.

Experiment 1

During Experiment 1, participants first went through a training phase in which the existing Crel (SAME/DIFFERENT) and Cfunc (COLOR/SHAPE) functions of known words were reinforced via a MTS task. Afterwards, these Crel and Cfunc stimuli (the unconditioned stimuli; USs) were paired with new neutral stimuli (the conditioned stimuli; CSs). In a final phase (i.e., the test phase), we examined whether the Crel and Cfunc functions of the USs had transferred to the CSs. This was investigated by using the CSs, rather than the USs, in an MTS task otherwise highly similar to that used in the training phase and checking whether the participants responded relationally in a correct manner.

Method

Participants

Thirty participants took part in the study (16 men, 14 women) with a mean age of 27.93 years (*SD* = 7.12, range 19-47 years). Participants were recruited via Prolific Academic (https://prolific.ac) and received a fee of £1.25 for their participation. Inclusion criteria were: 1) fluent in English; 2) a minimum of 90% approval rate for previous studies on Prolific; 3) no previous participation in similar studies from this research group.

Equipment and Materials

The study used an experimental task that the participants could perform at home on their personal computer, supported by Inquisit 5 Lab software. The instructions were presented on their computer screen and the entire experiment took approximately fifteen minutes to complete.

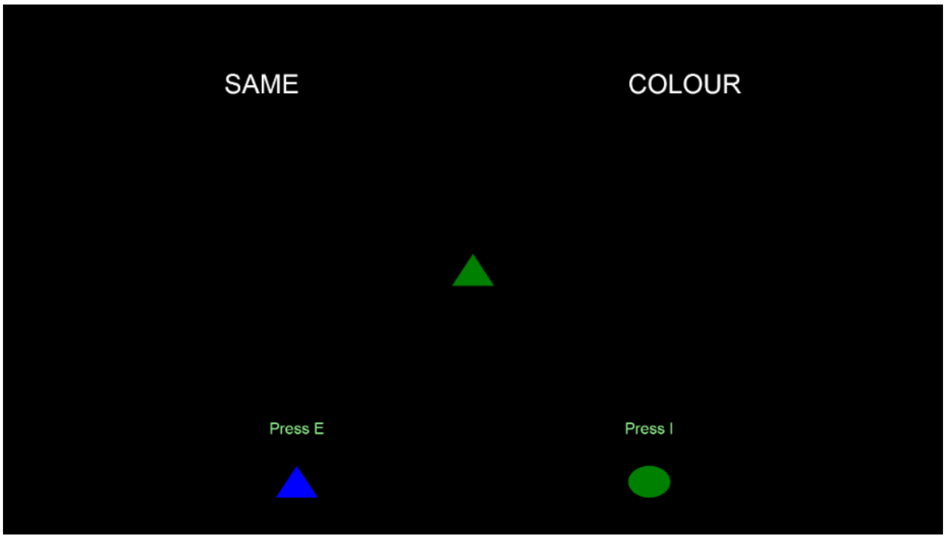
Procedure

The experiment consisted of a training phase, a learning phase and finally a test phase. In the training and test phases, a MTS task was used in which a Crel and Cfunc were presented together with a sample stimulus and two comparison stimuli.

Phase 1: Training Phase. The purpose of the training phase was to ensure that the participants understood how the MTS task worked. During this phase, up to three blocks of MTS trials were completed with each block containing 32 trials. A trial consisted of a sequence of the presentation of the Crel and Cfunc at the top of the screen, the sample stimulus in the middle and the comparison stimuli at the bottom (see Figure 1). Before starting this phase, participants were given the following instructions: *"The following task is a learning test. Each trial in this task contains five elements: At the top of the screen, two words. In the middle of the screen, a colored shape. At the bottom of the screen, two other colored shapes. Please note that these elements will change across trials. You will need to use the two words presented at the top of the screen to figure out how to respond on each trial. You will KEEP REPEATING this task until you have learned to respond VERY ACCURATELY. Your job is to figure out how to respond correctly. Speed is not important here. The only way you can learn this is by paying attention to the words at the top of the screen, and the feedback after each trial (i.e., "correct" or "wrong"). "*

Figure 1.

Example of a MTS Trial in the Training Phase



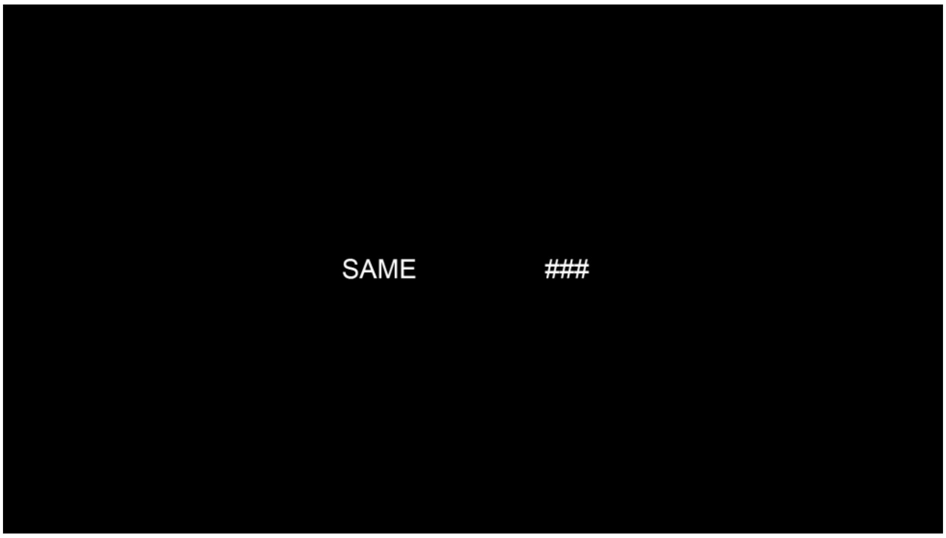
We used the words SAME, DIFFERENT, COLOUR and SHAPE as contextual cues given that these stimuli have Crel or Cfunc functions in everyday life. Each trial started with the presentation of a Crel in the upper left corner of the screen (SAME/DIFFERENT) and a Cfunc (COLOUR/SHAPE) in the upper right corner of the screen. After 250ms, this was followed by the presentation of the sample stimulus in the middle of the screen, below the contextual cues. The sample stimulus was a circle or a triangle with a blue or green color. Another 250ms later, the comparison stimuli appeared with a blue or green circle or triangle in the lower left and right corners, and ‘Press E’ and ‘Press I’, printed in green, above them, respectively. The stimuli remained on the screen until the participant had chosen a comparison stimulus by pressing the ‘E’ or ‘I’ button. Feedback was given after each answer. In case of a correct answer, CORRECT was displayed in the middle of the screen for 750ms. In case of an incorrect answer, WRONG was displayed for 2s. To complete the training phase and proceed to the learning phase, at least 28 trials out of 32 had to be correct. If not, another training block started. The MTS training phase was terminated if there were still less than 28 correct answers after the third training block.

There were four combinations of Crels and Cfuncs: SAME COLOUR, SAME SHAPE, DIFFERENT COLOUR, and DIFFERENT SHAPE. Similarly, there were four stimuli that could occupy both the function of sample stimulus and comparison stimulus, namely a blue triangle, a blue circle, a green triangle and a green circle. For each of the four sample stimuli, lists of all possible trials were made according to the four mentioned combinations of Crels and Cfuncs. Thus, there were 16 (4 x 4) lists in total. By combining all of the possible combinations with each comparison stimulus, we end up with eight possible trials for each list. From this, 128 (16 x 8) potential types of trials were possible. Two trials could contain the same stimuli and differ only with respect to the location (left or right) of the comparison stimuli. Per block, the participant was presented with 32 different trials. At least two of the eight trials from each of the 16 lists were selected. However, in a next block, it was possible that the same two trials from a list were presented as in the previous block. Thus, a block of 32 trials contained all possible combinations of Crels, Cfuncs and sample stimuli, and two of the eight possible combinations of comparison stimuli per list.

Phase 2: Learning phase. The learning phase consisted of three blocks of 20 trials, in all of which pairs of stimuli appeared. Before the start of the first block, participants were shown the following instructions: *"The next task will present pairs of words and symbols. Please observe these pairings carefully."* The order of the first two blocks was counterbalanced. In one of these blocks, the participant was alternately presented with two pairs (that were not counterbalanced), namely, SAME and ### (see Figure 2) or DIFFERENT and @@@. In the other block, the participant was now alternately shown COLOUR with *** and SHAPE with %%%. For all blocks, the words were always on the left of the screen and the symbols on the right. The final block also contained 20 trials and consisted of a combination of the trials from the first and second blocks. Specifically, the participants were offered in a random order 10 trials consisting of pairs of Crels and their related symbols and 10 trials consisting of pairs of Cfuncs and their related symbols.

Figure 2

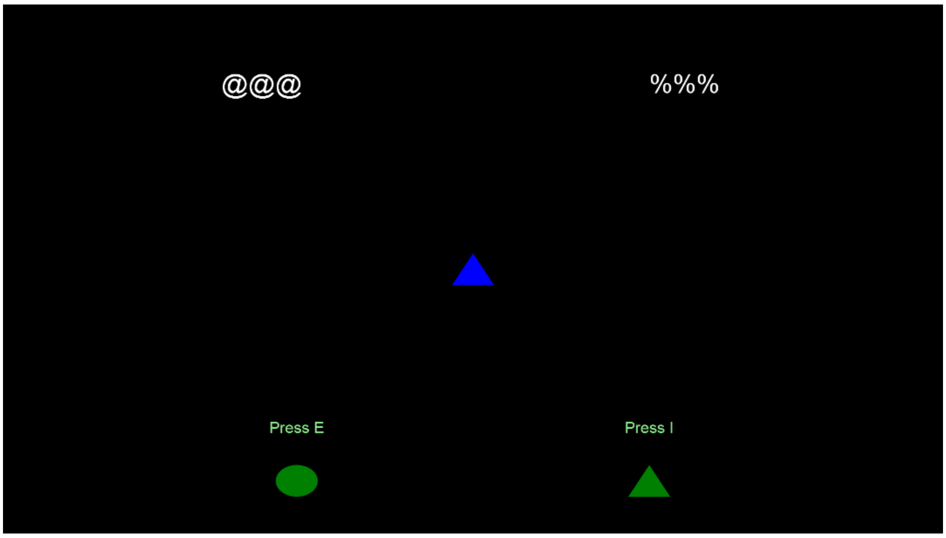
Example of a Stimulus Pairing with Crels during a Trial from the First Block of the Learning Phase.



Phase 3: Test phase. The test phase was similar to the training phase in that participants completed an MTS task. There were, however, several differences. First, the words that were presented as Crels (SAME/DIFFERENT) and Cfuncs (COLOUR/SHAPE) were replaced by the related symbols from the learning phase (see Figure 3). Second, no feedback was given after the participant's response. Third, the test phase consisted of a single block of 64 trials. Four trials from each of the 16 lists were given instead of two. Before the start of the test phase, the participants were shown the following instructions: *"The next task is similar to a previous one. Two new words will be presented on the top of the screen, and three shapes will appear in the middle and lower parts of the screen. You must respond with which shapes go together using information from the words at the top of the screen. THIS IS A TEST: no feedback will be presented after each trial. Speed does not matter in this test: just try to be as accurate as possible."*

Figure 3

Example of a Trial from the Test Phase.



Final questions. After these three phases the participants were asked five multiple choice questions. The first four were about the pairings during the learning phase to make sure the participants were paying attention. The following question was asked for each word (same/different/color/shape): *"Which symbol was paired with the word '…'?"* The response alternatives were each of the four different symbols, as well as 'I don't remember'. In this way we sought to assess which participants had learned that a particular symbol referred to a particular Crel or Cfunc. Finally, participants were asked how important psychological research is to them. This question was part of another, unrelated study.

Results

The transformation of Crel and Cfunc functions to the arbitrary stimuli is best assessed by inspecting the data from the subset of participants who paid attention to the stimulus pairing procedure. Therefore, only those participants who correctly answered the final questions about the pairings were included in the analyses. Five participants failed to answer the questions correctly. Their data were excluded from the analyses. This left 25 participants (13 men, 12 women) with a mean age of 27.44 years (*SD* = 7.01). Analyses that did include the data from the 5 excluded participants revealed the same effects and thus led to the same conclusions. All analyses were performed in *R* (version 4.0.2).

The mean proportion of correct responses during the test phase for each combination of Crels and Cfuncs is shown in Table 1. First, a one-sample t-test was performed. This showed that, as expected, the total proportion of correct answers during the test phase was significantly larger than chance (i.e., mu = 0.5), $t(24) = 26.18$, $p < .001$, $M = 0.94$, 95% CI [0.91, 1], $d = 5.24$. Next, we investigated whether the participants showed differences in the degree of learning depending on the identity of the Crel function (same or different) or the identity of the Cfunc function (color or shape). For this purpose, a within-subjects analysis of variance (ANOVA) was performed with the proportion of correct responses as the dependent variable and the identity of the Crel and Cfunc used as independent variables. We also carried out a Bayesian equivalent to this analysis in order to potentially quantify evidence for a null effect. No evidence was found for a statistically significant main effect of the type of Crel used on the number of correct answers, $F(1,96) < 1$, $p = .68$, $\eta^2_p = 0.002$. The Bayes Factor provided evidence for the absence of a main effect of Crel, $BF_{01} = 4.40$. Furthermore, we did not find a significant main effect of the type of Cfunc used on the number of correct answers, $F(1,96) < 1$, $p = .84$, $\eta^2_p = < 0.001$. The Bayes Factor indicated the absence of a main effect of Cfunc, $BF_{01} = 4.65$. Finally, the interaction effect was not significant, $F(1,96) = 1.27$, $p = .26$, $\eta^2_p = 0.013$. The Bayes factor for this analysis, however, did not provide evidence either in favour of, or against, the null effect, $BF_{01} = 2.26$.

Table 1

Mean Proportion of Correct Answers as a Function of Type Crel and Cfunc During the Test Phase

Crel	Cfunc	Mean *(SD)*
Same	Colour	0.97 (0.05)
	Shape	0.93 (0.08)
Different	Colour	0.93 (0.20)
	Shape	0.95 (0.10)

Discussion

Experiment 1 examined the simultaneous transfer of Crel control for sameness and difference and Cfunc control for color and shape. It used stimulus pairing as a way of transferring functions. The present experiment provides initial confirmation for the simultaneous transfer of these functions through stimulus pairing. The test phase showed that the total proportion of correct answers of the participants was significantly and substantially above chance. Moreover, the degree of transfer did not depend on the type of Crel or Cfunc which was used, indicating that this effect was not limited to a specific type of Crel/Cfunc.

Although the above results appeared to be independent of the specific type of Crel/Cfunc, the experiment still involved only two types of Crels and two types of Cfuncs. The question thus remains whether other Crels and Cfuncs can also be successfully learned via stimulus pairing. In addition, Experiment 1 has the limitation that the same comparison stimuli were used during training and test. This implies that participants could in principle have learned to relate stimulus constellations (e.g., a particular set of Crel, Cfunc, sample and comparison stimuli) to responses (press E or I) without learning the Crel and Cfunc functions. We therefore conducted a second experiment that attempted to overcome these limitations and extend the findings to comparative relationships, using the Crel stimuli BIGGER and SMALLER, and to other Cfunc stimuli, namely SIZE and VALUE. The generalization to other types of Crels and Cfuncs was therefore examined. We also examined whether newly acquired Crels and Cfuncs also influence responding to stimuli other than those used during training.

Experiment 2

The procedure for this experiment was identical to that of Experiment 1 with the following modifications. First, the Crel functions BIGGER and SMALLER and the Cfunc functions SIZE and VALUE were used, rather than SAME/DIFFERENT and COLOR/SHAPE. Second, we added a second part of the test phase in which the comparison stimuli were also replaced with novel exemplars in order to examine whether the Crels and Cfunc had an impact also on responding to novel stimuli.

Method

Participants

The sample consisted of 60 participants (30 women, 29 men, 1 person who did not specify a gender) with a mean age of 30.02 years (*SD* = 9.67, range 18 – 50 years). The recruitment process was identical to that of Experiment 1, with the addition of one exclusion criterion, namely participants who already participated in Experiment 1.

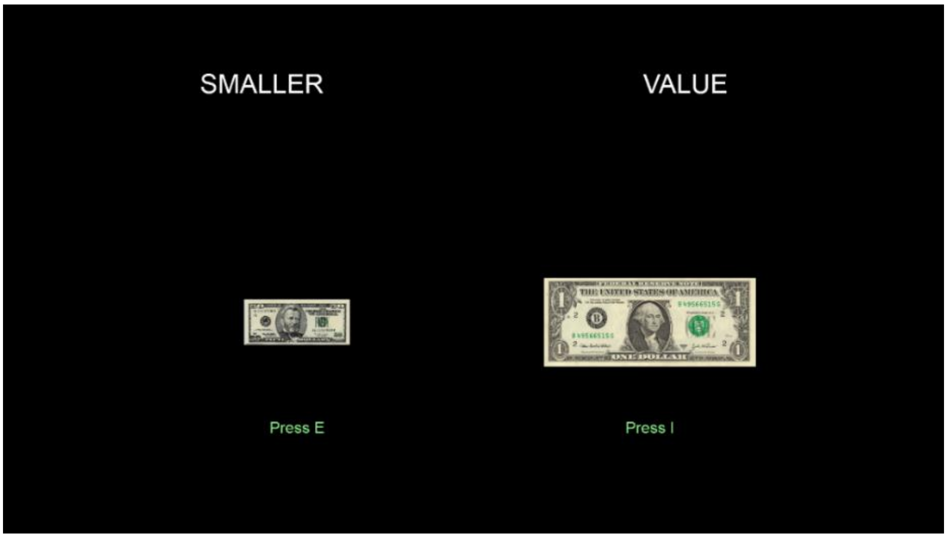
Equipment, Materials, and Procedure

Only differences with Experiment 1 will be described. Four stimuli (BIGGER, SMALLER, ### and @@@) were used as Crels and four stimuli (VALUE, SIZE, %%% and ***) were used as Cfuncs.

Phase 1: Training Phase. A trial consisted of the presentation of the Crel and Cfunc at the top of the screen and comparison stimuli at the bottom (i.e., no sample stimulus was presented; see Figure 4). On each trial, first a combination of a Crel and Cfunc was presented (e.g. SMALLER and VALUE; see Figure 4). After 500ms, comparison stimuli appeared with a small or large $1- or $50-dollar bill in the lower left and right corner with 'Press E' and 'Press I', printed in green, above them, respectively. We used four combinations of Crels and Cfuncs: BIGGER VALUE, BIGGER SIZE, SMALLER VALUE, SMALLER SIZE. Another four stimuli could take the function of comparison stimulus, namely, a small $1 bill, a small $50 bill, a large $1 bill, and a large $50 bill.

Figure 4

Example of a Trial in the Training Phase



Phase 2: Learning Phase. The learning phase was identical to that of Experiment 1 except that different words were used (i.e., BIGGER, SMALLER, VALUE, SIZE).

Phase 3: Test phase. The test phase consisted of two parts. During the first part, participants completed a block consisting of 32 trials in which the original combinations of Crels (BIGGER/SMALLER) and Cfuncs (VALUE/SIZE) were replaced by the related symbols from the learning phase (see Figure 5; see also test phase Experiment 1). Before the start of the test phase, the participants were shown the following instructions: *"The next task is similar to the first one you completed. Two symbols will be presented on the top of the screen, and two dollar bills will appear in the middle of the screen. You must respond using information from the symbols at the top of the screen. THIS IS A TEST: no feedback will be presented after each trial. Speed does not matter in this test: just try to be as accurate as possible."*

Figure 5

Example of a Trial from the First Part of the Test Phase.

When this part was completed, the participants moved on to the second part of the test phase in which another 32 trials were presented. The trials were similar to the first part of the test phase (see Figure 5), but now the comparison stimuli ($1 bill/$50 bill) were replaced by two new comparison stimuli, namely a $2 bill and a $20 bill, each of which was shown large or small. In this way, we examined whether the Crels and Cfuncs also influenced responding to other comparison stimuli. Before the start of the second part, the participants were given the following instructions: "*You will keep doing the same task as before. Two symbols will be* *presented on the top of the screen, and two dollar bills will appear in the middle of the screen. You must respond using information from the symbols at the top of the screen. THIS IS A TEST: no feedback will be presented after each trial. Speed does not matter in this test: just try to be as accurate as possible."*

Final questions. As in Experiment 1 four multiple-choice questions were asked about which symbols were paired with the words (bigger/smaller/value/size) during the learning phase.

Results

As in Experiment 1, only the data from participants who remembered which symbol had which function were included in the analyses. As a result, the data of 8 participants were excluded leaving the data of 52 participants (26 women, 26 men) with a mean age of 29.17 years (SD = 8.71). Analyses that did include the data from the 8 excluded participants revealed the same effects and thus led to the same conclusions.

Table 2 shows the mean proportion of correct answers per combination of Crel and Cfunc for the two parts of the test phase. Two one-sample t-tests were performed, for the first part (original training stimuli) and the second part of the test phase (novel stimuli). Regarding the first part, the total proportion of correct answers was larger than chance (0.5), $t(51) = 24.37$, $p < .001$, $M = 0.92$, 95% CI [0.89, 1], $d = 3.38$. The second part of the test, which assessed whether Crels and Cfuncs also influenced responding to new comparison stimuli, also showed that the total proportion of correct answers per participant was significantly and substantially higher than chance (0.5), $t(51) = 29.82$, $p < .001$, $M = 0.95$, 95% CI [0.92, 1], $d = 4.14$.

Table 2

Mean Proportion of Correct Answers as a Function of the Type of Crel and Cfunc for the First Part of the Test Phase (Original Comparison Stimuli) and the Second Part of the Test (New Comparison Stimuli)

Test phase	Crel	Cfunc	Mean (*SD*)
Original Stimuli	Bigger	Size	0.91 (0.16)
		Value	0.95 (0.13)
	Smaller	Size	0.92 (0.15)
		Value	0.92 (0.15)
Novel Stimuli	Bigger	Size	0.96 (0.11)
		Value	0.96 (0.13)
	Smaller	Size	0.95 (0.13)
		Value	0.93 (0.13)

Next, for the two parts of the test phase, we examined whether this successful transfer of Crel and Cfunc functions was moderated by the identity of the Crel function (BIGGER or SMALLER) or the identity of the Cfunc function (VALUE or SIZE). For this purpose, two within-subjects analyses of variance (ANOVA) were performed with the correct number of responses per combination of Crel and Cfunc as the dependent variable and the identity of the Crel used and the identity of the Cfunc used as independent variables. Again, a Bayesian analysis of variance was also performed. For the first part of the test phase, no evidence of a statistically significant main effect of the nature of Crel used was found, $F(1,204) < 1$, $p = .60$, $\eta^2_p = 0.001$, or of the nature of Cfunc used, $F(1,204) < 1$, $p = .45$, $\eta^2_p = 0.003$. The Bayes Factors indicated the absence of a main effect of Crel, $BF_{01} = 5.81$, and Cfunc, $BF_{01} = 5.03$, respectively. No significant interaction effect could be found either, $F(1,204) < 1$, $p = .45$, $\eta^2_p = 0.003$ with Bayes Factor-based evidence for the absence of an interaction effect, $BF_{01} = 4.03$. With respect to the test phase with novel comparison stimuli, we found a similar pattern of results: no significant effect of the identity of the Crel used, $F(1,204) = 1.53$, $p = .22$, $\eta^2_p = 0.007$, $BF_{01} = 3.22$, the identity of the Cfunc used, $F(1,204) < 1$, $p = .49$, $\eta^2_p = 0.002$, $BF_{01} = 5.31$, or of an interaction effect, $F(1,204) < 1$, $p = .49$, $\eta^2_p = 0.002$, $BF_{01} = 3.78$.

Finally, a paired samples t-test was conducted to examine whether the accuracy level of the participants was similar in the two parts of the test phase[1]. A significant difference was found between the overall proportion of correct answers during the first part of the test phase and during the second part of the test phase, $t(51) = -2.25$, $p = .029$, $M = -0.02$, 95% CI [-0.046, -0.0026], $d = 0.31$. The mean proportion of correct responses during the phase with novel comparison stimuli ($M = 0.95$) was unexpectedly higher than the mean proportion of correct responses during the first part of the test phase ($M = 0.92$).

Discussion

Experiment 2 extends the findings of Experiment 1 with evidence for the simultaneous transfer of relational and functional contextual control for comparative relations and the stimulus properties value and size, respectively. These Crels and Cfuncs were successfully used both during the first part of the test phase, with the original comparison stimuli, and during the second part, with the new comparison stimuli. In all circumstances, the total proportion of correct answers was significantly and substantially higher than chance. There was no evidence for an influence of the type of Crels and Cfuncs. This again implies Crel and Cfunc functions may be transferred simultaneously through stimulus pairings in a manner which generalizes across specific Crels and Cfuncs and produces generalizable control over operant responses. Interestingly, the accuracy level during the test phase with novel comparison stimuli was

[1] This analysis was exploratory in nature, and not part of our confirmatory analytic plan.

significantly higher than that of the test phase with the original comparison stimuli. This may have been because the test with the original stimuli was presented before the test with the novel stimuli. Although feedback was not given during the test phase, participants might have become more familiar with aspects of the testing procedure during the first phase, thus leading to less incorrect responses during the second phase.

General Discussion

The present study investigated whether and when Crel and Cfunc functions can be learned simultaneously through a stimulus pairing procedure. Previous studies examined the transformation of only one type of function (either Crels or Cfuncs). Moreover, the existing evidence for the transformation of Crel functions (e.g., McLoughlin & Stewart, 2017; Perez et al., 2017) and Cfunc functions separately (e.g., Stewart et al., 2013; Perez et al., 2015) was always obtained via the establishment of equivalence relations via MTS tasks.

Both our experiments started with a training phase in which the existing Crel and Cfunc functions of stimuli were reinforced in a MTS task (Experiment 1) or discrimination task (Experiment 2). Next, the participants went through a learning phase in which the Crels and Cfuncs (USs) were paired with new neutral stimuli (CSs). In the test phase, we examined whether the neutral stimuli had acquired the Crel and Cfunc functions by replacing the original contextual stimuli by the new neutral stimuli in the MTS or discrimination task. Because stimulus pairing appears to be suitable for the transfer of other contextual control functions (e.g., SD functions), we expected that Crel and Cfunc functions could also be transferred in this way. Experiment 1 provides evidence for the transfer of Crel functions for relational behavior based on sameness and difference, as well as the Cfunc functions color and shape. In other words, both relational and functional contextual control was exercised over physical stimulus features (color and shape). Experiment 2 generalized the findings of Experiment 1 to other types of Crels (bigger, smaller) and Cfuncs (value, size) and showed that those Crels and

Cfuncs also controlled responding to stimuli that were not involved in training. Although the most important finding is that the learning effect is clearly present for both parts of the test phase, in future studies, one could shed more light on this issue by counterbalancing the order of the block with the original training stimuli and the block with the novel comparison stimuli.

We did not find evidence in either experiment for an influence of the identity of Crels or Cfuncs. In fact, Bayesian analyses of variance showed evidence for the absence of these effects. The absence of main or interaction effects indicates that the degree of learning is the same for the different relations and functions that we looked at. The learning for the function of value in Experiment 2 is particularly interesting because, in contrast to the functions of color, shape and size, this function is verbal and arbitrary in nature. This is in contrast with the research of Stewart et al. (2013) and Finn and De Houwer (2021), who only considered contextual control over the physical characteristics of the stimuli. More specifically, Stewart et al. (2013) used the Cfuncs type of shape, number of shapes, size of dots and number of dots and Finn and De Houwer (2021) used speed and direction as Cfunc functions. In Experiment 2 we used the Cfuncs size and value which implies control over physical as well as non-physical characteristics of the stimuli.

It is also worth noting that studies using multiple contextual cues simultaneously (e.g., training Crels *and* Cfuncs) are generally scarce in the literature. Indeed, even in the case of Stewart et al. (2013), although Crel and Cfunc control was trained, only the transfer of Cfunc control was directly assessed. Finn and De Houwer (2021) also use multiple contextual control but focused on the selective action of Cfuncs (i.e., the capacity of these stimuli to exert control over the transformation of stimulus functions). Thus, both the studies of Stewart et al. (2013) and Finn and De Houwer (2021) are good examples of examining multiple contextual control, but both focused primarily on establishing Cfunc functions for novel stimuli. By contrast, our study examined the transformation of both Crel and Cfunc functions (i.e., the influence of existing Crel and Cfunc functions on novel stimuli). Beyond these specifics, it is critical to acknowledge that the training and assessment of multiple contextual cues is crucial for reaching the goal of a more naturalistic modeling of learning in the lab. As such, future work should follow the trend of our work here and focus on more comprehensive and elaborate learning contexts.

Although our research represents a promising push in the direction of studying more naturalistic learning environments, there is still much to be done. For example, Experiment 1 involved only physical functions and Experiment 2 both physical and arbitrary. Future research could make the bridge to examine the transfer of contextual functions in the case of Crels along with exclusively arbitrary Cfunc functions. Consider a learning context wherein two novel stimuli are paired with the Crels BETTER and WORSE, and two other novel stimuli are paired with the Cfuncs SOCIAL ESTEEM and PRICE (i.e., both arbitrary Cfuncs). If these arbitrary Cfunc functions are then transferred to the novel Cfunc stimuli, and these stimuli come to control participants' responses on a subsequent task, then this suggests that arbitrary forms of verbal responding can be acquired through simple stimulus pairing procedures. If this is the case, then it may well be the case that even arbitrary Crels and Cfuncs have similar functional properties to SDs (in additional to being acquirable through stimulus pairings), which in turn could provide researchers with further novel insights into complex verbal behavior.

As referred to earlier, other studies on the transfer of Crel and Cfunc features used methods like MTS tasks (e.g., Perez et al., 2017; Perez et al., 2015; Stewart et al., 2013). To the best of our knowledge, we are the first to investigate the transfer of these functions using stimulus pairings. The fact that stimulus pairings appear to be a very effective way of transforming Crel and Cfunc functions (as well as SDs and other stimulus functions) adds further credence to the idea that stimulus pairing represents a fundamental building block of human learning. Yet the conditions under which these functions are transformed are not yet clear. The question remains whether these conditions are the same for all functions that are transformed via stimulus pairing procedures. De Houwer and Hughes (2020) recently offered an overview of the known moderators of classical conditioning. For each of these moderators, future work could investigate whether they also affect the transformation of Crel and Cfunc functions via stimulus pairings. For example, in classical conditioning, contiguity between the US and the CS and statistical contingency between the stimuli are generally necessary for effects to occur, and it would be of value to examine whether this also applies to acquisition of Crels and Cfuncs via stimulus pairing. In addition, it might well be the case that the perseverance of learning effects differs: whereas classical conditioning effects for simple evaluative stimulus functions may last over time due to their simplicity, it may well be the case that Crel and Cfunc functions decay more quickly, and therefore further sessions may be required in order to sufficiently train such relations.

Conclusion

Whereas previous research found evidence for the transformation of Crel and Cfunc functions via equivalence relations established using MTS tasks, our research shows that also stimulus pairing is an effective channel for the transfer of these functions. The fact that other functions (e.g., SDs, reinforcing value) can also be transferred via stimulus pairing reinforces the conclusion that stimulus pairing is a fundamental building block of human learning. Moreover, the use of multiple contextual controls in our studies does justice to a more naturalistic form of learning. Future research should, among other things, emulate and extend on this more naturalistic approach, and focus even more on the control of exclusively arbitrary stimulus functions.

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