Stimulus Relations Can Have Stimulus Functions

Abstract

There is increasing consensus amongst researchers in different subfields of psychology that stimulus relations are an important determinant of human behavior. When we consider stimulus relations as elements of the environment like we do individual stimuli, we can study their various behavioral functions empirically. To our knowledge, little past research has done so in a systematic manner. We report on three preregistered behavioral experiments (N = 204) in which we set out to investigate whether stimulus relations can function as a conditional and unconditional stimulus using a passive pairing phase, and as a conditioned reinforcer using an operant (match-to-sample) conditioning procedure. Results in all three experiments supported our hypothesis that stimulus relations, both formal and symbolic, can have these functions. Implications for future research are discussed.

Keywords: Stimulus Relations, Conditioned Reinforcement, Conditional Stimulus, Unconditional Stimulus, Relational Responding

Over the past decades, there has been increasing consensus across psychological research that relational reasoning is central to human cognition and behavior (e.g., Hayes et al., 2001; Penn et al., 2008; Halford et al., 2010; Gentner & Smith, 2013; McLoughlin et al., 2020). Myriad examples can be found of typical human behavior that is guided by relations between events or objects in our environment (see Hughes & Barnes-Holmes, 2016a, 2016b, for many such examples). When hungry, you might pick the larger snack option at the bar. When trying to reach a destination, you decide which street to take based on where one is relative to a destination. These are examples of relations defined by our perception of the physical world that surrounds us, but humans are also (uniquely) capable of responding to symbolic relations that are defined not by formal (i.e., grounded in the physical world) stimulus properties, but by social convention. For instance, when asked to choose between a dime and a nickel, people familiar with US currency are likely to select the dime because it is larger than a nickel in terms of monetary value, even though it is smaller than a nickel in terms of physical size. Stimulus relations are a particularly important guide to behavior because any particular relation (e.g., identical to, larger than) can be applied to many different stimuli (e.g., any pair of identical shapes, regardless of the kind of shape; any pair of objects that differ in size, regardless of the kind of object).

In the current paper, we set out to examine in a systematic way whether stimulus relations can have a variety of stimulus functions. We will first explain what we mean with the term “stimulus functions” and then specify what exactly we mean with the term “stimulus relations”. A substantive body of prior research demonstrated that individual stimuli can have a variety of stimulus functions (Catania, 2013; De Houwer & Hughes, 2020). Take the example of an operant conditioning study with rats in which a red stimulus signals that pressing a lever will be followed by food. The food can be said to function as a reinforcer (Sr) if the relation between lever pressing and food results in an increase in the frequency of lever pressing. The red stimulus (e.g., a red light) can be said to function as a discriminative stimulus (Sd) if the rat is more likely to press the lever in the presence of a red stimulus than in its absence. In the context of classical conditioning, a stimulus (e.g., the sound of a bell) is said to function as a conditional stimulus (CS) if responses to the stimulus change as the result of stimulus pairings (e.g., bell-food). Likewise, a stimulus (e.g., food) is said to function as an unconditional stimulus (US) if it influences responses to the CS (e.g., the sound of a bell) it is paired with.

We were inspired by the idea that, at a descriptive level, stimulus relations are not that different from individual stimuli and could thus also have a variety of stimulus functions (see De Houwer & Hughes, 2020, p. 186). Any research on the functions of individual stimuli has to start with a description of the stimuli by the researcher. Take the aforementioned example of the operant conditioning study with rats in which a red stimulus signals that pressing a lever will be followed by food. In order to set up this study, researchers need to describe/operationalize what qualifies as a red stimulus. They can do so by making explicit the criteria they use. For instance, a red stimulus can be described as any stimulus that reflects light with a wavelength of approximately 625–750 nanometers. Once the stimulus has been described in this way, it can be examined what functions it has for the rat (e.g., whether it functions as an Sd; see above).

Examining whether stimulus relations can also have stimulus functions requires that one specifies at the descriptive level the criteria that determine whether a particular relation is present. For instance, researchers can describe/operationalize an identity relation as any event in which two individual stimuli have the same shape (e.g., two circles, two squares, or any other two identical shapes) and a difference relation as any event in which two stimuli have a different shape (e.g., a circle and a square). Moreover, rather than using criteria that refer to physical features (e.g., shape), researchers can also use criteria that refer to symbolic features (i.e., meaning). For instance, an identity relation can be described as two words that are similar in meaning (e.g., beautiful and attractive) and an opposition relation can be described as two words that have an opposite meaning (e.g., beautiful and ugly). As is the case with individual stimuli, once researchers have described what counts as a stimulus relation, they can examine which functions the stimulus relation has for a particular organism. In the example of the operant conditioning study described above, researchers could study whether the relation between the color of two individual stimuli (e.g., having the same color) functions as a Sd (as opposed to an individual red stimulus). One might define the *same color* relation as a difference in the wavelength of light reflected of the two stimuli smaller than two nanometers (and thus, the *different color* relation as any difference in wavelengths larger than two nanometers). The procedure could be set up so that lever pressing is reinforced only when the color of two lights presented above the lever is the same. If the probability of lever pressing is significantly higher when the difference in wavelengths is smaller than two nanometers (regardless of the particular color or wavelength) compared to when that difference is larger than two nanometers, this supports the conclusion that the relation “same color” functions as a discriminative stimulus.

To the best of our knowledge, there is little research that examined in a systematic and explicit manner whether stimulus relations can have a variety of stimulus functions. Instead, prior research on stimulus relations examined primarily whether stimulus relations influence the functions of other stimuli. For instance, when picking the larger of two snack options, the size relation between the two snacks determines which snack is selected. Of course, this also says something about the function of stimulus relations. Assuming that picking a snack is an operant response (i.e., is determined by outcomes such as caloric value), one could say that the stimulus relation functions as an Sd in this context (i.e., the fact that the first option is larger than the second influences the choice because it signals that selecting the first option will result in more calories). Match-to-sample (MTS) studies showed that stimulus relations can indeed acquire an Sd function. In a typical MTS study, participants are presented with a sample stimulus at the top of the screen and two comparison stimuli at the bottom of the screen. Imagine that participants are reinforced for selecting the comparison stimulus that is identical to the sample. In such studies, the identity relation functions as a Sd: it influences which comparison stimulus is selected because it signals which selection will be reinforced. However, this type of research was primarily intended to examine how stimulus relations influence the functions of other stimuli. Little or no attention was given to the fact that it also demonstrated that stimulus relations can function as a Sd. [1,2]

One reason for examining more explicitly whether stimulus relations can have a variety of functions is that stimulus relations can be very abstract and thus apply to many topographically different situations. For instance, defining an identity/similarity relation descriptively as any two stimuli that have the same shape creates a very large class of stimulus pairs that can have any possible shape (e.g., two circles, two squares, two hexagons, and so on). Hence, it can be examined whether the stimulus functions acquired by a subset of these stimulus pairs (e.g., circles and squares) generalize to other, untrained stimulus pairs (e.g., triangles or blobs).

We therefore conducted three learning studies that examined various stimulus functions of stimulus relations. In Experiment 1, we tested whether a stimulus relation could acquire the function of a conditioned reinforcer through an operant (MTS) learning phase. In Experiments 2 and 3, the goal was to investigate whether relations can function as a CS and US, respectively, by means of a classical conditioning procedure. In Experiments 1 and 2, the stimulus relation was described in terms of physical features. In Experiment 3, it was described in terms of meaning. In Experiments 1 and 2, we also tested whether the acquisition of a stimulus function generalizes to stimulus pairs that were not used in training to demonstrate that the function is in fact acquired by the relation (i.e.,

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[1] Researchers who were inspired by Relational Frame Theory (RFT; Hayes et al., 2001) have been particularly active in research on stimulus relations. In doing so, they focused on symbolic stimulus relations, that is, stimulus relations that are not grounded (solely) in physical stimulus features (e.g., size, color) but in meaning. However, also RFT research focused on how (meaning-based) stimulus relations influence the function of individual stimuli (i.e., transformation of function) rather than the functions of stimulus relations as defined descriptively by the researcher. In fact, when RFT researchers talk about (derived) stimulus relations, they are actually referring to (derived) relational responding, that is, the fact that the behavior of organisms is a function of (meaning-based) stimulus relations. In contrast, we use the term "stimulus relations" only at the descriptive level (i.e., as specified by the researcher) and refer to functions of stimulus relations when talking about the functions that a stimulus relation has for the organism whose behavior is analyzed.

[2] In relational MTS studies (e.g., Premack, 1983), the participant is presented with a pair of sample stimuli (AA), and two pairs of comparison stimuli (e.g., BB and BC). Selecting the comparison pair between which the same relation holds as the sample pair (in this example, BB) is reinforced. In this case, it is the relation between relations (i.e., are both pairs of identical or different stimuli) that has a function akin to that of an Sd (see De Houwer & Hughes, 2020, pp. 186). More specifically, the relation between relations influences responding to a relation (i.e., whether participants should pick the pair of identical stimuli or the pair of different stimuli).

whether the stimuli are identical or not, regardless of the particular stimuli being related), and not by the individual stimuli or stimulus features between which the relation holds.

Experiment 1

Reinforcement is an increase in the frequency (or likelihood) of a behavior as a function of its past consequences, the reinforcing stimulus or *Sr* (Skinner, 1938). Importantly, behavior is often guided by conditioned reinforcers (see Williams, 1994; Donahoe & Palmer, 2022, for reviews) that acquired their reinforcing function through past learning experiences. It is therefore important to understand which other events can acquire this reinforcing function. Virtually all research on conditioned reinforcement has considered individual stimuli as conditioned reinforcers (e.g., the clicking sound of a pellet feeder in an operant chamber, or tokens in Token Economies) but, as argued by De Houwer and Hughes (2020, p. 186), more complex events like stimulus relations might also acquire a reinforcing function from experience. Experiment 1 was designed to test whether stimulus relations (i.e., symbol identity match or mismatch, regardless of which particular symbols) can be established as conditioned reinforcers in a match-to-sample (MTS) procedure in which positive feedback was contingent on selecting a cue for monetary gain in the presence of either identical or non-identical symbols (the gain-relation). In a subsequent test phase, we tested for (a) increased frequency of responses that produced previously seen instances of the gain-relation (i.e., evidence for reinforcement); (b) increased frequency of responses that produced unseen instances of the gain-relation (i.e., evidence that the relation, and not the individual symbols that constitute the relation, functioned as reinforcer); and (c) whether participants were capable of accurately reversing the training contingency without explicit feedback (i.e., evidence for symmetry).

Method

Participants and Design

80 participants (33 women) aged between 18 and 58 years old (*M* = 33, *SD* = 10.51 years) were recruited on Prolific Academic (www.prolific.com). Criteria for inclusion were having English as first language, normal or corrected-to-normal-vision and no prior participation in studies by our lab. Sample size was determined based on effect sizes and attrition rates in previous experiments in this line of research[3]. The smallest effect size observed in previous experiments was Cohen's *d* = 0.4. *A priori* power analysis (G*Power 3.1; Faul et al., 2009) demonstrated that a sample size of N = 49 allowed us to detect effects (one-sample t-test) as small as Cohen's *d* = 0.4 with .80 power. Because

[3] The experiment we describe here is the final in a series of preregistered experiments. In four previous studies, conducted as part of a student's project, methodological errors and inconsistencies complicated the interpretation of results. To present our research concisely and clearly, we set up a fifth replication study that accommodated the issues. We report only this fifth study here. Preregistration documents, descriptions of the methods, analyses and results, materials and scripts to run the experiments and analyses for those four studies are available on OSF (https://osf.io/8dk2y/?view_only=b24dfd49b3fd4f4dbe4bcca43ba1837f).

the attrition rates in previous experiments ranged between 27 and 38 percent, we decided to recruit eighty participants. All participants provided informed consent before starting the experiment and were reimbursed £7.50/h for their participation (twenty minutes on average).

Materials

Stimuli. Two separate stimulus sets (Supplementary Materials) were used in the training blocks and the first test block versus the last two test blocks, respectively. Each set consisted of six pairs of identical (e.g., "^ ^") ASCII-symbols and eighteen non-identical (e.g., "^ &") pairs. Participants' earnings were indicated by written instruction (i.e., "*You earned 1 point.*" vs. "*You earned 0 points!*"). Response options varied for each block type: the 'E'- and 'I'-keys were used in the Sr-training, the 'left' and 'right'-arrow keys were used in the MTS procedures, the 'up'- and 'down'-arrow keys in the reinforcement blocks and the left mouse button in the generalization blocks.

Software. The experiment was programmed in and controlled by Inquisit 5 software (retrieved from https://www.millisecond.com, 2020). Data were analyzed using R (version 3.6.1; the R Core Team, 2019). Reproducible scripts for running the experiment and analyses were preregistered to the Open Science Forum (OSF) prior to data collection[4].

Procedure

After providing informed consent and demographic information, participants were informed that their goal was to earn as many points as possible, and that points would be converted to a monetary bonus after the experiment. They then started a sequence of training and test blocks.

Outcome (Sr) Preference Assessment. A first block assessed whether the instructions used to indicate gain (i.e., "*You earn 1 point.*") versus no gain (i.e., "*You earn 0 points.*") functioned as a reinforcer and punisher, respectively (i.e., above-chance selection of response that produced gain). Participants were instructed to learn which response delivered points. On every trial, the instruction to "*Press 'E' or 'I'*" was presented in the center of the screen until a response was registered. Responses were differentially reinforced: one followed by the gain instruction, the other by the no gain instruction, presented for 1500ms (Figure 1, A1). The relation between key presses (i.e., "E" or "I") and reinforcement was counterbalanced between participants. After 16 trials (1000ms inter-trial-interval; ITI), the number of points earned was presented on the screen. Participants who earned at least 13 points (binomial probability of passing by chance < .01) proceeded to the next block. Others completed up to two more training blocks. We preregistered that participants who failed to reach the performance criterion within three blocks would be excluded from analyses (but none did, see

[4] https://osf.io/skehm/?view_only=a755d30fd37b4d43b12001194822165b

Results).

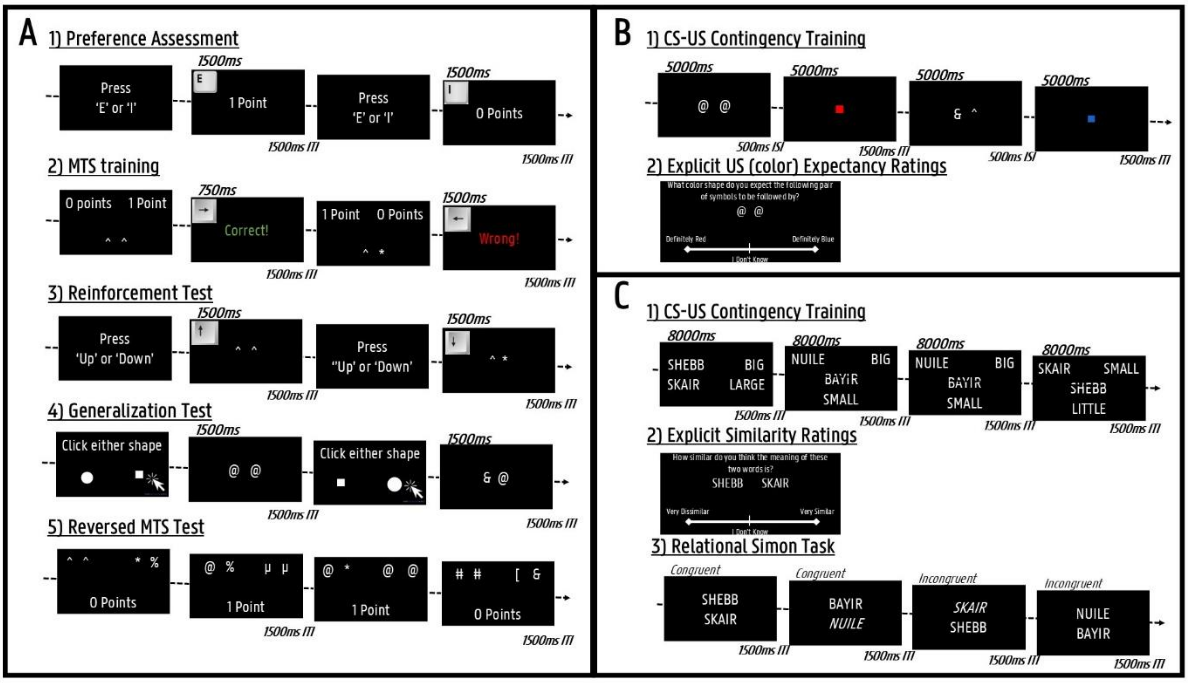

***Figure 1**. Procedure flowcharts for Experiments 1, 2 and 3. (**A**) In Experiment 1, participants preferences for the established reinforcer cue are assessed in a differential reinforcement procedure (A1), following which they learn to match relations (between a pair of symbols) to the reinforcer and punisher cues in a match-to-sample task (A2). We then evaluate the reinforcing properties of the seen symbol-pairs (A3) and generalization of these properties to a set of novel pairs and responses (A4). Finally, we evaluate whether participants can produce the symmetrical relations entailed by the trained contingencies in a reversed MTS task (A5). (**B**) In Experiment 2, participants first experience a contingency between the presentation of a relation (between symbols) and the subsequent presentation of a colored shape (B1). Thereafter, they are asked to rate which color they expect to follow a given pair of (seen or unseen) symbols (B2). (**C**) In Experiment 3, participants are repeatedly presented with two pairs of words, a pair of non-words and a pair of synonyms or antonyms (C1). We then ask them to rate how similar they think the meaning of the nonwords in each pair to be (C2) and have them perform a relational Simon task (C3).*

Relation-Outcome MTS-training. Participants then completed a MTS-task (Figure 1, A2), in which reinforcement (i.e., "*Correct*") was contingent on selecting either gain or no gain in the presence of identical or non-identical symbols, to establish the identity relation as a conditioned reinforcer. Participants were instructed that they would see a pair of symbols presented in the center of the screen, and to try to correctly select which number of points (i.e., the gain or no gain instruction) presented at the top of the screen goes with each pair of symbols. On every trial (500ms ITI), first, a pair of identical or non-identical symbols sampled from Stimulus Set 1 was presented in the center of the screen for 500ms, followed by the gain and no gain instructions presented at the top left and top right of the screen (location randomized across trials) until a response was registered. Participants responded using the "LEFT" or "RIGHT" arrow-key, respectively, and were presented a "C*orrect*" (green font, 750ms) vs. a "*Wrong*" (red font, 1500ms) feedback message after responding. Between subjects (counterbalanced), we manipulated whether selecting the gain instruction in the presence of an identical versus a non-identical pair, and the no gain instruction in the presence of the other relation produced a "*Correct*" feedback message (which we hereafter refer to as the gain- and no-gain-relations, respectively). We refer to these contingencies as the identical-gain vs. the non-identical-gain condition, respectively. Participants completed up to five blocks of sixteen trials. When participants responded correctly on at least 13 trials within a block, or completed five blocks without reaching the criterion, they progressed to the test phase.

Reinforcement and Generalization Test. We then tested whether the relation exemplified by the symbol pairs seen in the relation-outcome MTS had acquired the function of Sr. In the first two blocks of 20 trials (1000ms ITI), participants were instructed to "*press 'UP' or 'DOWN'*" (i.e., using the arrow-keys) on every trial. Each response was followed by the 1500ms presentation of either a pair of identical or non-identical symbols sampled from Stimulus Set 1 (Figure 1, A3). The mapping of responses to outcomes was counterbalanced between participants. Subsequently, they moved onto two more blocks of 20 trials (1000ms ITI) that assessed generalization of the Sr function to novel exemplars of the same relation (Stimulus Set 2) and novel responses. On every trial, a circle and a triangle (equal surface area) were presented on the left- and right-hand side of the screen (location randomized across trials) below a message instructing the participant to select one of the shapes using the mouse (Figure 1, A4). Each response was followed by the 1500ms presentation of either an identical or non-identical pair (counterbalanced between participants). At the end of each block, participants were asked to guess how many points they earned on a slider, after which their actual score was presented and they progressed to the second block of 20 trials (identical to the previous).

Reversed MTS Test. A final MTS-test phase was included to test for the symmetry of the previously trained relation between gain vs. no gain instructions and identical vs. non-identical symbol-pairs. In this block (40 trials, 1000ms ITI), the sample and comparison stimuli were reversed relative to the contingency in the Relation-Outcome MTS training. First, the instruction for either gain or no gain was presented as the sample in the middle of the screen. After 500ms, an identical and non-identical symbol-pair sampled from Stimulus Set 2 were presented as comparison stimuli at the top-left and -right side of the screen (location randomized) until a response was registered (Figure 1, A5). Participants were instructed to select a symbol pair using the 'left'- and 'right"-arrow keys, as a function of the instruction presented in the center. No feedback was provided. Responses in line with the contingencies experienced in the Relation-Outcome MTS training (i.e., the identical-gain or non-identical-NID-gain condition) were considered correct in analysis.

Analyses and Results

We hypothesized that the relations would acquire the function of conditioned reinforcer in the operant training, which would be evidenced by an increased frequency of responses producing the gain-relation in subsequent test blocks. We tested the frequency of those responses against chance using a one-sample t-test, and report Cohen's *d* effect sizes with 95% confidence intervals to aid interpretation of the effect. As per the preregistration, we excluded data from participants who failed to reach the accuracy criterion in the Sr-Training (i.e., 13/16 correct responses within three blocks) and Relation-Outcome MTS (i.e., 13/16 correct responses within five blocks) tasks. No participants failed to reach the Sr-training criterion (13/16 correct), indicating that the gain instruction (i.e., "*You earn 1 point.*") functioned as a (established) reinforcer. However, 28 participants (i.e., 35%) failed to reach the preregistered MTS-training accuracy criterion within five blocks. Their exclusion resulted in an analytic sample of 52 participants (22 women; mean age = 31.29, *SD* = 10.46 years).

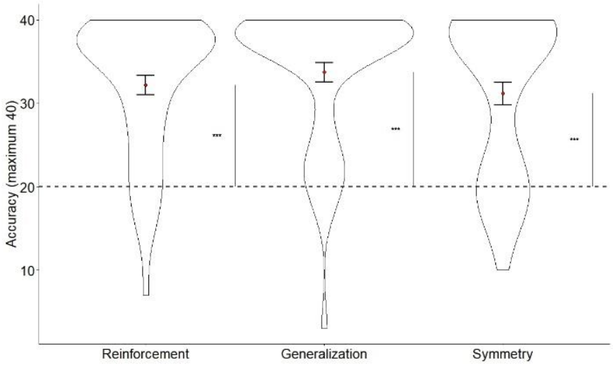

Figure 2. *Violin plot showing distribution and means of participants' response accuracy in the three testing blocks, compared to chance-level (dashed line). Error bars represent standard error around the mean.* ***Note****: ***: p < .001.*

Results are summarized in Figure 2. In the reinforcement blocks, participants selected the response that produced the gain-relation on average 32.17 out of 40 trials (*SD* = 8.26, modal value = 38). A (two-tailed) one-sample t-test indicated that this was significantly more than chance: $t(51.00) = 10.63$, $p < .001$, $d = 1.47$, 95% *CI* = [0.85, 2.10]. Similarly, in the generalization block, participants responded for the gain-relation (*M* = 33.71, *SD* = 8.38, modal value = 39) significantly above chance-level: $t(51.00) = 11.80$, $p < .001$, $d = 1.64$, 95% *CI* = [0.99, 2.28]. This effect did not differ significantly between Contingency 1 and 2 (i.e., for identical vs. non-identical symbols; two-sample t-test *p*'s > .282). Finally, participants' accuracy (*M* = 31,15, *SD* = 9.64, modal value = 39) in reproducing the symmetrical counterparts of the trained contingencies in the reversed MTS task was significantly higher than chance: $t(51.00) = 8.34$, $p < .001$, $d = 1.16$, 95% *CI* = [0.56, 1.76].

Discussion

Our results supported the hypothesis that stimulus relations can acquire the function of conditioned reinforcer through operant contingencies. Reinforcing the selection of a (already established) reinforcer (i.e., a gain instruction) in the presence of a relation in an operant MTS-training phase led to an increased frequency of responses producing the 'gain-relation' in subsequent testing blocks for participants achieving performance criterion in training. Furthermore, participants also more frequently responded to produce novel instances of those relations, made up from stimuli not encountered before in the learning phase. This result further supports the claim that it was in fact the identity relation, and not the stimuli involved in it, that acquired the reinforcing function. It is worth noting the generativity of our procedure to establish a relation as a conditioned reinforcer via operant contingencies, instantiating this same function for various other instances of the same relation that have not been trained directly. It would be interesting for future research to investigate the extent of this generalization. That is, does the reinforcing function generalize to instances of the same relation between other stimulus properties, and even symbolic relations, or is it limited to those stimulus properties related in training. Finally, participants successfully selected the correct relations in the presence of the gain or no gain instruction, indicating the symmetry of the relation between the instructions and identity-relations. This provides partial evidence for stimulus equivalence (Sidman, 2009), and can explain how relations might acquire stimulus functions (i.e., participants come to act as if the relations instantiated between symbol-pairs are equivalent to the gain instruction, resulting in the transfer of the reinforcing function from the latter to the former).

Experiment 2

One of the seminal empirical findings in the history of learning psychology was the observation that organisms develop a conditioned response (CR) after repeatedly experiencing the presentation of a US (e.g., food) contingent on the presentation of a CS (e.g., a bell; Pavlov, 1927). As noted above, a stimulus can be said to function as a CS if the responses it evokes change as the results of CS-US pairings. Classical conditioning has been considered as an explanatory model for how humans come to develop preferences (e.g., Levey & Martin, 1975; De Houwer, 2007; Moran et al., 2023; but see also De Houwer & Hughes, 2016, for a symbolic perspective), fears and phobia's (e.g., but see also Boddez et al., 2021, for a symbolic perspective). Much like the literature on (conditioned) reinforcement, most experimental research on classical conditioning in the lab has considered the effects of contingencies in the presence of an individual CS and an individual US. However, given the prominent role stimulus relations play in governing behavior, one might wonder if there also exist instances of such learning effects wherein relations have the function of a CS or US. For example, one might form a preference or aversion for 'sameness' after pairs of identical objects have been repeatedly followed by a positive or fearful stimulus, respectively (i.e., the relation acquires the valence of the US after repeated pairings). Alternatively, two events may come to be considered as more similar or more different after being repeatedly paired with pairs of identical or non-identical stimuli (i.e., the relation functions as a US of which the relatedness transfers to the CS). Experiment 2 addressed the question whether stimulus relations, again exemplified by pairs of identical or non-identical symbols, can function as a CS in a Pavlovian conditioning procedure.

Method

Participants and design

Fifty-two participants (21 women; mean age = 36.75; *SD* = 13.47 years) were recruited on Prolific Academic applying the same inclusion criteria as in Experiment 1. All participants provided informed consent and were paid £1.5 (i.e., ca. £9.00/h). Sample size was determined based on *a priori* power analysis (G*Power 3.1, Faul et al., 2007), to achieve .8 power to detect a main effect as small as Cohen's f = 0.2 in a 2x2 repeated measures ANOVA.

Materials

Stimuli. The same stimulus sets of symbol pairs were used as exemplars of relations which served as conditional stimuli in the learning phase. A blue and red square were used as the two unconditional stimuli.

Software. The experiment was programmed in and controlled by labjs software (javascript and html; Henniger et al., 2018, https://lab.js.org/). Data were analyzed using the same R packages as in Experiment 1. Reproducible scripts for running the experiment and analyses were preregistered to the OSF prior to data collection[5].

Procedure

Learning phase. After providing informed consent and demographic information, participants started the learning phase and were instructed that they would see "*pairs of symbols presented on the screen, followed by colored shapes"* and they were expected "*to learn which symbol pairs are followed by which shape.*" They were further instructed to "*pay close attention to what is presented on the screen, as you will be asked to respond in a particular way on some trials.*" In four blocks of 12 trials (500ms ITI), the presentation of a blue or a red square (US1 and US2, 3000ms) was contingent on the prior presentation (300ms ISI) of a pair of either identical or non-identical NID symbols (CS1 and CS2, 3000ms; Figure 1, 2A). In every block, all twelve pairs constituting Stimulus Set 1 were presented once. After every tenth trial, an attention check trial was inserted where the words "PRESS SPACE" were presented instead of symbols. Participants who responded within 3000ms were deemed to have passed the check and received positive feedback ("Thank you for paying attention!", in green), whereas slow responders were presented negative feedback ("Too slow. Please pay attention!", in red). After pressing the spacebar, the next trial started after a 1500ms ITI.

US expectancy ratings. To assess the predictive value (for the color of the US) of the identity relations, participants were asked to rate "*Which color shape would you expect the symbol pair below to be followed by?"* for all symbol pairs seen in training (i.e., Set 1), and a set of unseen symbol pairs (i.e., Stimulus Set 2) to test for generalization (i.e., 24 ratings in total, Figure 1, 2B). Every trial presented at the top of the screen the question above a symbol pair, and in the middle of the screen a scale ranging from "*Definitely red*" to "*Definitely blue*" (with the midpoint labeled "*I don't know*"; scale encoded as [0; 100] with 0.1 increments). Participants indicated their response using the mouse and clicked a submit button presented at the bottom of the screen to rate the next symbol-pair.

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[5] https://osf.io/xtdmj/?view_only=27ef418074194527886b2f185cde7603

Analyses and Results

Data from all participants were analyzed. Participants' ratings for the 24 symbol-pairs were collapsed into four within-subjects conditions, as a function of the color of the US that the relation (i.e., symbol-pair) was followed by (red or blue) and the stimulus set that the pair was a part of (training versus generalization, Figure 3). Data were analyzed using a 2x2 repeated measures ANOVA. Our hypothesis that stimulus relations do indeed acquire the function of a CS would be supported by the observation of a main effect of US-color (i.e., the response is conditional on the experienced CS-US contingency) in the absence of a main effect of stimulus set (i.e., the relation, not the symbol pairs themselves, has acquired the function). For the trained exemplars, participants did indeed rate CS1 (followed by a blue square) as significantly more likely to be followed by a blue square (M_{rating} = 20.00; *SD* = 32.34) and CS2 by a red square (M_{rating} = 80.63, *SD* = 32.06). Ratings for the unseen symbol-pairs showed a similar trend: M_{rating} CS1 = 22.12 (*SD* = 29.02) vs. M_{rating} CS2 = 76.10 (*SD*= 29.5). ANOVA results showed that the main effect of US color was significant: $F(1, 153) = 154.66$, $p < .001$, $\eta_p^2 = .99$. The main effect of stimulus set did not reach significance ($p = .665$), nor did the interaction effect ($p = .336$).

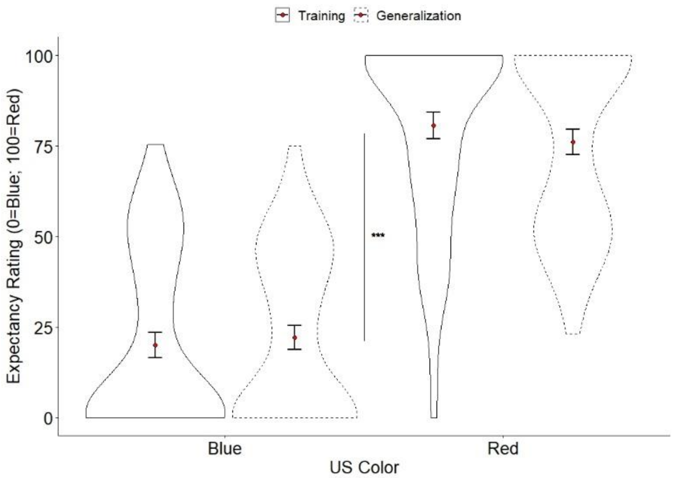

Figure 3. *Violin plot showing distribution and means of self-reported color expectancy ratings of trained (black) and novel (grey) instances of relations, grouped by the contingency in training (paired with red or blue square). Error bars represent standard error around the means.* ***Note****: *** = p <.001.*

Discussion

The results support our hypothesis that stimulus relations can acquire the function of CS in a Pavlovian conditioning-like procedure. The main effect of US color evidences the fact that the predictive value of the stimulus relation is conditional on the learning phase contingency (i.e., our definition of a CS; De Houwer & Hughes, 2020). Furthermore, the absence of a main effect of stimulus set suggests that it was not the symbols forming pairs themselves, but the identity relationship between them that acquired the CS function. The fact that the interaction effect also did not reach significance further supports the latter conclusion. An interaction might suggest the existence of a generalization curve like commonly seen in instances of Pavlovian conditioning such as fear conditioning (e.g., Dymond et al., 2015; Boddez et al., 2021).

Of course, we wish to make clear that this represents merely a proof-of-concept study. Given that our only outcome measure were participant-reported ratings, which are sensitive to social desirability and demand effects, first on the agenda is to replicate these findings and find converging evidence using different measures (e.g., implicit measures or behavioral measures like an approach-avoidance task). Many important questions are still open for future research to address. We tested whether relations can become predictive of stimulus colors due to repeated pairings, but predictiveness other functions like fear, disgust or valence may be more interesting to study from a clinical perspective. Second, our results provide initial evidence for the generalizability of stimulus functions, but our design was not suited to properly address whether the function generalizes to formal relations between other stimuli (i.e., not symbols) or even between conceptual categories, and to what extent this is like generalization observed in fear or evaluative conditioning. Finally, research must also address other moderators of this effect (e.g., does it extinguish, can it be counter conditioned, are awareness of the relation and the contingency a necessary condition, and so on).

Experiment 3

Experiment 3 investigated whether stimulus relations can also function as a US. As noted in the introduction, a stimulus can be said to function as a US if pairing it with another stimulus (i.e., the CS) results in a change in responding to that other stimulus. In the current experiment, we tested whether we could alter participants' judgements of the similarity of pairs of nonsense words by repeatedly presenting them together with pairs of either synonyms or antonyms, and afterwards asking participants to rate the (semantic) similarity of words in a pair. Analogous to EC effects, in which valence transfers from a positive or negative stimulus to a previously neutral stimulus as a result of repeated pairings, we expected the semantic similarity of synonym or antonym pairs to transfer to the pairs of nonwords. Second language acquisition may involve many such instances, where one might learn the meaning of a new word (e.g., *chaud* means hot in French) and learn that it is related to another (opposite to *froid*) in the same way as hot and cold. Without ever experiencing these French words in real life, one can now correctly open the correct faucet in France to get a glass of cold water.

Method

Participants and design

Seventy-two participants (39 identified as women, four as non-binary, and 30 as men; M_{age} = 34.51 years, SD_{age} = 12.17 years) were recruited on Prolific Academic applying the same inclusion criteria as in Experiment 1. All participants provided informed consent and were paid £1.5 (i.e., ca. £9.00/h). Sample size was determined based on *a priori* power analysis (G*Power 3.1, Faul et al., 2007), to achieve .8 power to detect a main effect as small as Cohen's *d* = 0.3 using a one-tailed, dependent sample t-test.

Materials

Stimuli. Four nonwords (i.e., shebb, skair, nuile and bayir) were combined into two pairs (counterbalanced between participants) representing CS1 and CS2. Ten pairs of synonyms (big-large, small-little, hot-warm, cold-chilly, hard-tough, rich-wealthy, smart-intelligent, old-aged, fast-speedy, easy-simple) and tens pairs of antonyms (up-down, night-day, rich-poor, summer-winter, old-young, sick-healthy, strong-weak, fast-slow, right-left, hot-cold) served as USs.

Software. The software used for Experiment 3 was the same as that described for Experiment 2. Preregistered experiment and analysis scripts are available on the OSF[6].

Procedure

Learning Phase. After participants provided informed consent and demographic information, they were instructed that they would "… *see two pairs of words presented on the screen, but some words are from a language you probably don't know*." And to "… *learn about the word pairs they don't know, based on what is presented on the screen.*" As in Experiment 1, they were also instructed about attention checks. The learning phase had four blocks of ten trials (500ms ITI) on which a CS was presented with a US. During each trial, the non-word pair constituting CS1 or CS2 (randomized) was presented on the left-hand side (one word above the other) and a pair of synonyms or antonyms was presented on the left and right side of the screen (i.e., also one above the other) respectively for 5000ms. The location of the words within a pair (i.e., top or bottom) was balanced across the learning phase for both CSs and USs. After every ninth trial, an attention check trial was inserted on which, instead of the CS and US, the words "PRESS SPACE" were presented twice (same topography as other trials). Participants who responded within 3000ms were deemed to have passed the test and received positive feedback ("Thank you for paying attention!", in green), whereas slow responders were presented negative feedback ("Too slow. Please pay attention!", in red). After pressing the spacebar, the next trial started after a 1500ms ITI.

Explicit Similarity Ratings. Participants were then asked to rate how similar they thought the two words constituting CS1 and CS2 were. On two separate trials the question was presented at the top of the screen, CS1 or CS2 presented below it (randomized) , and a scale ranging from 'Very dissimilar' over 'I don't know' to 'Very Similar' (encoded [0; 100], 0.1 increments) on which to indicate their rating with the mouse in the center of the screen.

Implicit Relational Simon Task. As an additional, exploratory question (preregistered), we assessed whether the contingencies participants experienced in the learning phase were sufficient to also affect automatic relational processing. To this end, we also included an adapted extrinsic relational Simon task (Spruyt et al., 2007). Participants were instructed that they would see a "*pair of*

[6] https://osf.io/tkgmh/?view_only=fc2a7e12cfd84372bc90c2bd67dbe62f

words presented on every trial, one above the center and one below." And that "*the font of the words will vary across trials, and that it is important they pay close attention to this!*". They were then instructed that "*to base your responses on the font of the words: press the F key if they are printed in the same font, and the J key if they are printed in a different font.*" Participants then proceeded to a practice block (32 trials), followed by four test blocks (64 trials each).

Every trial, a fixation cross (i.e., '+') was first presented in the center of the screen for 500ms, followed by the presentation of a pair of words, one word above and one below the location of the fixation cross (no longer presented). We balanced the location of individual words in a pair (i.e., top versus bottom), the letter case of individual words (i.e., upper- versus lowercase), the perceptual relationship between the words (i.e., same versus different letter case) and the semantic relationship between the two words (i.e., synonyms vs. antonyms). In this way, we can distinguish between congruent trials, on which the task-relevant and task-irrelevant relation are the same, and incongruent trials, where they are different (e.g., synonyms presented in the same versus a different letter case, respectively). When participants responded incorrectly, a feedback message (i.e., 'INCORRECT!', in red) was presented in the center of the screen for 2000ms. Correct responses were not followed by a feedback message. When participants failed to respond within 3000ms, another feedback message (i.e., 'TOO SLOW!') was presented for 500ms (after the 'INCORRECT' message in case of an incorrect response). The inter-trial-interval varied randomly between 500 and 1500ms. During practice, the words were pairs of synonyms (big-large, small-little) or antonyms (big-small, large-little), each presented an equal number of times, whereas in the test blocks, the CSs (i.e., pairs of nonwords) from the learning phase were presented on half of the trials (i.e., instead of synonyms or antonyms).

Analyses and Results

Participants' similarity ratings of the two word pairs constituting CS1 and CS2 were pooled and analyzed using a paired samples t-test. We hypothesized participants would rate the nonwords constituting CS1 (repeatedly paired with synonyms in the learning phase) as more similar than those constituting CS2 (repeatedly paired with antonyms). Participants' rated the non-words making up CS1 as rather similar (M_{CS1} = 65.01, *SD* = 34.04), a rating that was significantly higher than the midpoint of the scale: one-sample $t(67) = 3.72$, $p < .001$, $d = 0.44$, 95% *CI* = [-0.04, 0.91]. Participants rated nonwords making up CS2 as rather dissimilar (M_{CS2} = 28.21, *SD* = 31.82), a rating that was significantly lower than the midpoint of the scale: $t(67) = -5.78$, $p < .001$, $d = -0.68$, 95% *CI* = [1.16; -0.20]. The paired-sample t-test showed that ratings for CS1 and CS2 differed significantly: $t(71) = 6.49$, $p < .001$, Cohen's $d = 1.11$, 95% *CI* = [0.68; 1.54].

As noted, we had no strong reason to believe that implicit measures would also show an effect, and thus the measure was preregistered as exploratory. As preregistered, we analyzed RT data for the trials involving nonwords (i.e., half of the test trials) using a linear mixed model with congruency (congruent vs. incongruent) and Stimulus (CS1 vs. CS2) as fixed factors, and random intercepts for subject and trial (using the *robustlmm* package in R; Koller, 2016). The binary accuracy data were analyzed using a generalized linear mixed (binomial) model of the same structure. Analysis of log-transformed RT data revealed significant main effects of task congruency, $t(9773) = 9.3$, p < .001, and stimulus, $t(9773) = 8.6$, p < .001, as well as a significant interaction effect, $t(9773) = 14.2$, p < .001. On average, participants responded faster on incongruent (*M* = 745ms, *SD* = 142ms) trials than on congruent trials (*M* = 756ms, *SD* = 145). Figure 4 illustrates the interaction effect: for CS1 (paired with synonyms), we observe the expected effect (mean RT congruent = 735ms, *SD* = 159ms; mean RT incongruent = 790ms, *SD* = 186ms), but for CS2 (paired with antonyms; mean RT congruent = 821ms, *SD* = 200ms; mean RT incongruent = 724ms, *SD* = 140ms). Variance on the estimates of the random subject and trial intercepts were small, suggesting participants and trials did not differ much in their baseline reaction times. Analysis of the accuracy data revealed no significant effects (all p < .17). Participants were very accurate on both congruent (*M* = 96.7%, *SD* = 4.5%) and incongruent trials (*M* = 96.8%, *SD* = 4.4%). Here too, variance on the estimates of the random subject and trial intercepts were small, suggesting participants and trials did not differ much in their baseline reaction times.

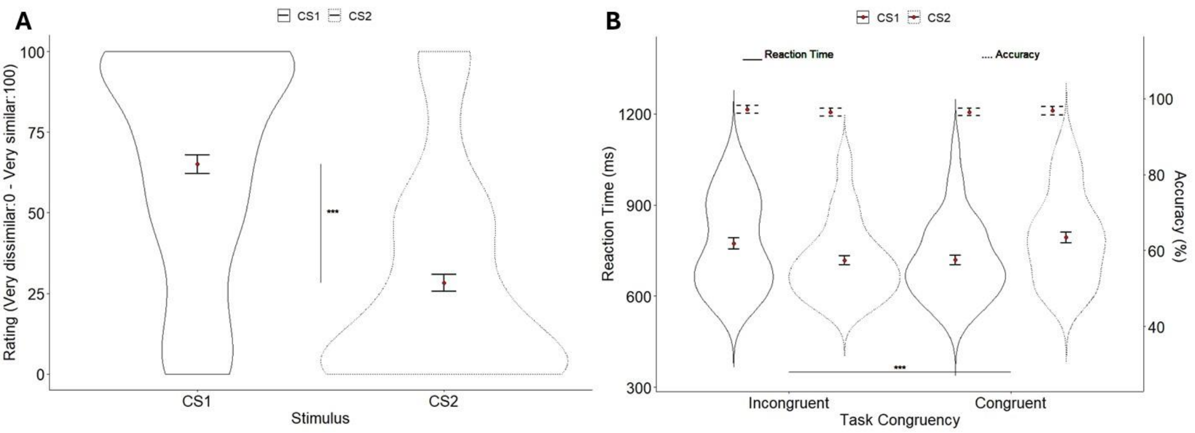

Figure 4. *Experiment 3 results.* ***A****: Violin plot illustrates distribution and means of self-reported similarity ratings for nonword pairs CS1 and CS2.* ***B****: Violin plot illustrating distribution and means for reaction times in the relational Simon task, for each CS in the congruent and incongruent condition. Error bars (second legend: reaction times and accuracy) represent standard error around the mean. Accuracy means and standard errors are plotted as dashed error bars.* ***Note****: *** = p < .001.*

Discussion

The results reported above provide evidence that stimulus relations can have the function of a US, influencing responding to a previously neutral CS. As opposed to Experiments 1 and 2, the relation in question is not defined by physical stimulus features, but by the meaning of the stimuli, as defined by the researcher. We showed that participants' ratings of the similarity of two unknown words were significantly altered by presenting them together with pairs of synonyms or antonyms, demonstrating that the relation between the (meaning of the) words has the function of a US. While we did not include a pre-rating in our design, the used nonwords were selected from a previous rating study in our lab that showed participants did not encounter them before and rated them as neutral. Moreover, the word pairs' composition was counterbalanced between participants, so we have no reason to suspect participants would have judged them as similar or dissimilar in this way already before the learning phase.

As an exploratory measure, we also included a relational Simon task to assess the transfer of the semantic relation (synonym or antonym) to novel stimuli resulting from the learning procedure. If the experienced pairings were indeed sufficient to affect implicit relational processing (beyond explicit judgements), we would expect to observe a significant effect of stimulus-response congruency in the relational Simon task. That is, participants should be slower and make more errors due to interference on incongruent tasks (e.g., respond to different letter case of two nonwords previously paired with synonyms; see Spruyt et al., 2007, for a more detailed discussion). Results of our analysis are not easily interpretable. No effects were observed on accuracy data, with participants generally showing ceiling effects across conditions. We did observe a significant effect of congruency on RTs, but in the opposite direction than we would have expected (i.e., participants responded slower on congruent trials). Closer inspection of the interaction between congruency and stimulus pair revealed that for CSs paired with synonyms, the congruency effect emerged as expected, whereas for the CS paired with antonyms, it trended significantly in the opposite direction. One interpretation of these results is that there are differences in the transfer of different relations. It could be that equivalence relations transfer more easily than other relations, but this would not explain why the opposite (as opposed to an attenuated) effect was observed. This may be explained by considering that the pairing of nonword pairs and pairs of antonyms not only failed to instantiate an opposition relation between the nonwords, but instead still served to establish an equivalence relation. If that were the case, the congruency of the trials involving this CS would be reversed, and reaction times would reflect an effect in the expected direction. Given the exploratory nature of this measure, we refrain from making strong assumptions here, and instead suggest that future research addresses the moderators of this complex learning effect, for example using other measures (e.g., MTS procedures) to show that other relations than equivalence can indeed transfer (and if so, investigating moderators of these effects).

General Discussion

In this paper, we reported three studies that examined the functions of descriptive stimulus relations (i.e., the relation between features of stimuli as defined by the researcher). Our results showed that descriptive stimulus relations can function as a conditioned reinforcer, a conditional stimulus and an unconditional stimulus. These studies supplement earlier research that was not explicitly directed at examining the stimulus functions of stimulus relations but did show that stimulus relations can have Sd functions. We can thus conclude that stimulus relations can have a variety of stimulus functions.

The results of Experiments 1 and 2 also showed that newly acquired functions of stimulus relations can generalize to instances of those relations that were not involved in training. This observation might be relevant for those interested in influencing behavior (e.g., through an experimental manipulation or a clinical intervention), as a relatively short learning phase may facilitate the acquisition of a function for a broad stimulus class. Indeed, any novel set of events between which the relation is subsequently established may acquire said function too.

Our studies also pave the way for future research. One open question is the extent to which stimulus functions generalize to other instances of the relation that has acquired a novel stimulus function. In Experiments 1 and 2, we tested generalization of the acquired (conditioned reinforcer and conditional stimulus) functions to other instances of that relation, but those tests still assessed stimulus relations in the same modality (or domain) as those seen in training. It would be interesting for future research to assess whether these acquired stimulus functions also generalize to instances of the same relation instantiated in entirely different stimuli or events (e.g., the identity-relation between shapes, colors, size, or conceptual similarity relations). Furthermore, research on generalization of classical conditioning effects has demonstrated generalization of conditioned fear, not only across perceptual, but also conceptual or symbolic stimulus dimensions (e.g., Dunsmoor & Murphy, 2015; Vervliet & Boddez, 2020; Boddez et al., 2021; see also Hughes et al., 2016, for related work in evaluative conditioning). In light of the current findings, future research should address whether functions acquired by stimulus relations also generalize across perceptual (e.g., other pairs of identical objects) or symbolic (e.g., other synonyms) dimensions.

Future research can also look into the moderators of the observed learning effects. This can involve manipulations of procedural aspects (e.g., passive versus operant, length, strength of contingency) but it can also look at functional properties such as the extent to which the acquired functions of stimulus relation are sensitivity to extinction and counterconditioning. More generally, all questions that have been asked about the acquisition and role of stimulus functions of individual stimuli can also be asked about the acquisition and role of stimulus functions of stimulus relations (De Houwer & Hughes, 2020, pp. 185-190). In sum, we hope the research presented here provides the start of a systematic line of research on the stimulus functions of descriptive stimulus relations.

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Author Contributions

Contributed to conception and design: MR, JDH, MF

Contributed to acquisition of data: MR

Contributed to analysis and interpretation of data: MR

Drafted and/or revised the article: MR, JDH, MF

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Competing Interest

None.

Data Accessibility Statement

All experiment plans, hypotheses, methods and scripts were preregistered and are available on the open science framework (Experiment 1: https://osf.io/skehm/?view_only=a755d30fd37b4d43b12001194822165b; Experiment 2: https://osf.io/xtdmj/?view_only=27ef418074194527886b2f185cde7603; Experiment 3: https://osf.io/tkgmh/?view_only=fc2a7e12cfd84372bc90c2bd67dbe62f). The repositories also contain raw and processed data.