CROSS-DOMAIN ANALOGIES AS RELATING DERIVED RELATIONS AMONG TWO SEPARATE RELATIONAL NETWORKS

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Contemporary behavior analytic research is making headway in analyzing analogy as the establishment of a relation of coordination among common types of trained or derived relations. Previous studies have been focused on within-domain analogy. The current study expands previous research by analyzing cross-domain analogy as relating relations among separate relational networks and by correlating participants' performance with a standard measure of analogical reasoning. In two experiments, adult participants first completed general intelligence and analogical reasoning tests. Subsequently, they were exposed to a computerized conditional discrimination training procedure designed to create two relational networks, each consisting of two 3-member equivalence classes. The critical test was a two-part analogical test in which participants had to relate combinatorial relations of coordination and distinction between the two relational networks. In Experiment 1, combinatorial relations for each network were individually tested prior to analogical testing, but in Experiment 2 they were not. Across both experiments, 65% of participants passed the analogical test on the first attempt. Moreover, results from the training procedure were strongly correlated with the standard measure of analogical reasoning.

Key words: analogical relations, derived stimulus relations, relational frame theory, matching to sample, relational network

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Analogy is broadly described as the relating of two situations based on sharing a common pattern of relationships among their constituent elements (e.g., Holyoak, 2005). Both situations may pertain to the same domain (i.e., within-domain analogy) or may belong to two unrelated domains (i.e., cross-domain analogy). An example of a within-domain analogy is solving a problem concerning the treatment of a stomach tumor by means of comparing it to the way a cardiologist successfully treated a cardiopathy. For instance, a regular physician would recognize the analogical relations by virtue of having studied common elements between various stomach and heart diseases. Alternatively, an example of a cross-domain analogy is solving the stomach tumor problem by comparing it to the way a general captured a fortress (e.g., Duncker, 1945; Gick & Holyoak, 1980). In this case, the physician would recognize analogical relations between situations that have not been previously related but are, however, functionally equivalent. In either case, both types of analogies usually lead to the transfer of information from one domain (e.g., the cardiopathy or the fortress problem) to the other domain (e.g., the stomach tumor problem). This type of generativity has been defined as the most relevant feature of analogical reasoning (e.g., Hoyoak & Thagard, 1995; Stewart, Barnes-Holmes, Hayes, & Lipkens, 2001) and is viewed as one of the most important and sophisticated aspects of human cognition (e.g., Hesse & Klecha 1990; Polya, 1971; Skinner, 1957; Stewart et al., 2001). Indeed, analogical abilities are commonly used as a metric of intelligent behavior (e.g., Spearman, 1923) and are considered to have a very relevant role in areas such as problem-solving or the achievement of scientific discoveries (e.g., Hesse, 1966; Holyoak & Thagard, 1995).

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Empirical studies based on cognitive theories of analogical reasoning (e.g., Gentner, 1983; Holyoak, 1985; Holyoak & Thagard, 1989; Sternberg, 1977) have shown some descriptive data pertaining to many of the features of this type of reasoning (see Holyoak, 2005 for a review). However, because these accounts are generally structuralistic, they do not specify the history that is needed for developing an analogical reasoning repertoire. In addition, these analyses are not focused on isolating analogical reasoning from other types of responding (e.g., Carpentier, Smeets, Barnes-Holmes, & Stewart, 2004; Lipkens & Hayes, 2009; Stewart et al., 2001). For instance, Carpentier et al. (2004) have demonstrated that the four-term analogy tasks (i.e., *a* is to *b* as *c* is to *d*) used in key studies in the cognitive development literature (e.g., Goswami & Brown, 1990) can be solved based on the b-term alone. In other words, participants could respond correctly without taking into account the *a* and *c* terms. For example, participants solved the analogy ''spider is to web as bee is to hive/honey/ant/fly'' (i.e., they selected hive) even when ''spider'' and ''bee'' were substituted by the letters X and Y.

In the last decade, alternative research on analogical reasoning has been conducted within Relational Frame Theory (RFT; Hayes, Barnes-Holmes, & Roche, 2001). RFT is a behavior analytic approach to human language and cognition. The main idea behind RFT is that relating stimuli under arbitrary contextual control (i.e., to relate stimuli that do not share formal properties) is a type of generalized operant that is learned through multiple exemplar training. RFT proposes the existence of different types of relations among stimuli or relational frames such as coordination, distinction, opposition, comparison, hierarchy, etc. Every relational frame has three properties: mutual entailment, combinatorial entailment and transformation of functions. Mutual entailment involves the bidirectionality of stimulus relations: If A is related to stimulus B, then B is related to A. Combinatorial entailment means that two or more stimuli that have acquired the property of mutual entailment can be combined: If A is related to B and B is related to C, then A is related to C. Transformation of functions means that a change in the function of one member of a relational network also can change the function of the other members of the network. In other words, given that the relations A–B and B–C have been trained, if A acquires a reinforcing function, then the B and C functions will be affected according to the specific type of relations that have been established between them.

From an RFT point of view, analogy involves the establishment of a relation of coordination among common types of trained or derived relations (e.g., Lipkens, 1992; Stewart et al., 2001). In a pioneering experimental study, Barnes, Hegarty, and Smeets (1997) showed that participants related derived relations of sameness and distinction pertaining to the same relational network. Participants in Experiment 1 learned eight conditional discriminations using a one-to-many delayed-matching-to-sample procedure using nonsense syllables as arbitrary stimuli (A1B1, A1C1, A2B2, A2C2, A3B3, A3C3, A4B4, and A4C4). Typically, the sample appeared in the center of the screen (e.g., A1). Pressing any key removed it and the four comparison stimuli appeared (e.g., B1, B2, B3, and B4). Selecting the correct comparison (i.e., B1) was followed by positive feedback while selecting an incorrect comparison (i.e., B2, B3, or B4) was followed by negative feedback. Consequently, participants learned not only relations of sameness (e.g., A1 same as B1) but also a myriad of trained or derived relations of distinction (e.g., A1 different from B2, B3, or B4). Combinatorial relations of sameness (i.e., B1C1, B2C2, B3C3, B4C4, C1B1, C2B2, C3B3, and C4B4) were then tested without feedback. Finally, analogical tests followed with two types of trials: similar–similar and different–different trials. In the similar–similar trials, the sample was always a compound stimulus formed by a combinatorial relation of sameness (e.g., B1C1) and the two comparisons were one combinatorial relation of sameness (e.g., B4C4) and one of distinction (e.g., B3C4). Different–different trials were the same, except that the sample was a combinatorial relation of distinction. Participants were required to relate the compounds formed by the same type of derived relations by matching either a sample combinatorial relation of sameness to another one of sameness or by matching a sample combinatorial relation of distinction to another one of distinction. All the 6 participants, including a 12 year-old child, eventually responded correctly to the test. The procedure of Experiment 2 was identical but without testing the combinatorial relations before the analogical test. Again, all 6 participants, including a 9-year-old child, passed the test.

Several subsequent studies have extended this analysis of within-domain analogy. Carpentier, Smeets, and Barnes-Holmes (2002, 2003) showed that 5-year-old children had considerable difficulties responding correctly to a similar experimental analogical test but 9-year-old and adult participants did not. These results are consistent with the data from the developmental literature on analogical reasoning that have shown that children younger than 9 years have difficulties solving even the simplest analogies (e.g., Levinson & Carpenter, 1974; Sternberg & Nigro, 1980). Consequently, the emergence of the performance in this type of experimental procedure seems to follow a similar developmental trend as that of analogical reasoning. Barnes-Holmes et al. (2005) added reaction time and event-related potentials (ERPs) measures and showed that participants responded significantly faster to similar–similar than to different–different trials and that the waveforms of the two response patterns in the left-hemispheric prefrontal regions were significantly different. Additionally, the ERP data were fully consistent with the findings in the neurocognitive literature on analogy (e.g., Luo et al., 2003). Lipkens and Hayes (2009) showed that participants successfully recognized and produced analogies based on opposite and comparison relations. Additionally, they used trained relations to form new relations among pairs of novel, previously unrelated stimuli by analogical means (e.g., a sameness relation trained between A1 and B1 was applied to train a sameness relation between two previously unrelated stimuli, A2 and B2). Stewart, Barnes-Holmes, Roche, and Smeets (2002) showed that relating derived relations allowed the discrimination of a physical similarity between the relations involved. In addition, this transformed the functions of a task. For example, participants who previously sorted a series of wooden blocks according to color instead of according to shape were exposed to an analogical test in which all trials involved the discrimination of common shapes. After that, participants changed the way they sorted the blocks (i.e., they sorted according to shape).

These studies, among others, have significantly advanced in the functional analysis of within-domain analogies based on relating derived relations within the same relational network (see reviews in Stewart & Barnes-Holmes, 2004; Stewart, Barnes-Holmes, & Weil, 2009). However, no published study has analyzed cross-domain analogies (i.e., relating relations among separate relational networks). Analyzing cross-domain analogies is relevant for several reasons. First, cross-domain analogies seem to be more difficult to produce and recognize in view of the data from cognitive research. For instance, Keane (1987) showed that solving the stomach tumor problem was more probable when participants were provided with a story about how a surgeon destroyed a brain tumor (i.e., within-domain analogy) than when they were provided with a story about how a general destroyed a fortress (i.e., cross-domain analogy). Second, this type of analogy has more generative potential because it allows the transfer of knowledge or skills that were learned in one domain to another unrelated domain (e.g., Gentner, 2003) and, accordingly, it has been related to creativity (e.g., Costello, & Keane, 2000; Holyoak & Thagard, 1995; Sternberg, 1997). Finally, cross-domain analogies are especially common in daily life and in applied settings such as political debate (Blanchette & Dunbar, 2001), the production of scientific hypotheses (Dunbar & Blanchette, 2001), teaching science (Bassok & Holyoak, 1989), psychotherapy (e.g., Hayes, Strosahl, & Wilson, 1999), etc.

The present study aims to advance the functional analysis of cross-domain analogies. Our main objective is to design a procedure that allows the recognition of analogical relations among two separate relational networks. However, our interest is that participants recognize this type of analogy on the first attempt, which was unusual in the preceding experiments. Because people often establish analogies with apparent ease (e.g., Dunbar & Blanchette, 2001), establishing experimental analogies on the first attempt would prove to have more ecological validity than establishing them after several attempts as similar studies have previously allowed (e.g., Barnes et al., 1997; Barnes-Holmes et al., 2005). Additionally, it has been shown that participants can learn to respond to this type of analogical test even in the absence of explicit feedback (Pérez & García, 2008). Therefore, it seems that establishing analogies on the first attempt should be a step forward in isolating the interactions involved in this type of emergent behavior. The secondary aim is to analyze the validity of this model of analogical reasoning by correlating participants' performance with a standard measure of analogical reasoning. Two consecutive experiments were conducted. In the first one, after testing the combinatorial relations of each relational network, participants were asked to derive analogical relations among the two networks.

EXPERIMENT 1

Method

Participants

Twelve undergraduates attending different courses (psychology, education, business studies, etc.) at Universidad de Almería participated in the experiment (age range = 18–24 years; 8 females, 4 males). All participants were recruited through in-class announcements and on-campus flyers. None of them had previous experience with the procedures employed in this study nor had any previous knowledge of stimulus equivalence research/RFT literature. Upon completing their participation, all participants received a canteen voucher exchangeable for a breakfast or snack.

Design and Variables

The experiment had two parts. In Part I, participants responded to two standard intelligence tests, a general test and another specifically focused on analogical reasoning (see intelligence measures section). In Part II, participants were exposed to the experimental procedures across five phases as shown in Figure 1. In Phase 1, six conditional discriminations with stimuli from Series 0 were trained. In Phase 2, participants were exposed to a test consisting of relating the trained sameness and distinction relations directly trained in Phase 1. These two phases with Series 0 were conducted to bring participants' behavior under the control of the relevant cues of the analogical test format. In Phase 3, participants were trained on four conditional discriminations with the stimuli of Series 1 and another four with the stimuli of Series 2. Series 1 and Series 2 stimuli never appeared together on the same trial. Stimuli of both series were also physically dissimilar (see next section) in order to avoid the establishment of relations based on nonarbitrary properties. Combinatorial relations of both series were tested in Phase 4 and finally, in Phase 5, participants were exposed to the analogical test, which contained two parts. The first part involved relating combinatorial relations of sameness while the second involved relating combinatorial relations of distinction.

Setting, Instruments and Stimuli

The experiment was conducted in a laboratory consisting of two adjacent rooms (an experimental room and an observation room) of equal size (4 × 3 m). The experimental task was conducted on an HP nx9010 laptop computer with a 15-inch color screen that was programmed with Visual Basic 6.0© to present visual stimuli as well as to record participants' responses on the tasks.

The visual stimuli were black shapes framed in a white 6 × 6 cm square background, presented on a general grey background. Stimuli are shown in Figure 2. They were nine nonsense syllables (Series 0), nine abstract shapes (Series 1) and nine Greek letters (Series 2). Alphanumerical labels (e.g., A1, B1, C1, etc.) are used to identify the stimuli; however, these labels were not presented to the participants.

Intelligence Measures

D-70 (Dominoes Test; Kowrousky & Rennes, 2000). D-70 was originally designed to evaluate one's skill in conceptualizing and applying systematic reasoning to problems and to assess one's ability to comprehend abstract relations, which is a central function of intelligence. It is a nonverbal and nonmanipulative test that is considered a good measure of the *g* factor (i.e., general intelligence: a single factor that is common to different intelligence tests) for medium and high academic levels. It presents 44 items of increasing difficulty. One of the simplest items is to complete the sixth domino of the following series: 1–1, 2–2, 3–3, 4–4, 5–5, ?–?. We used the Spanish adaptation by TEA Ediciones, which reported Cronbach's alphas between .82 and .89. The mean score found for university students was 29.98 (SD = 6.58).

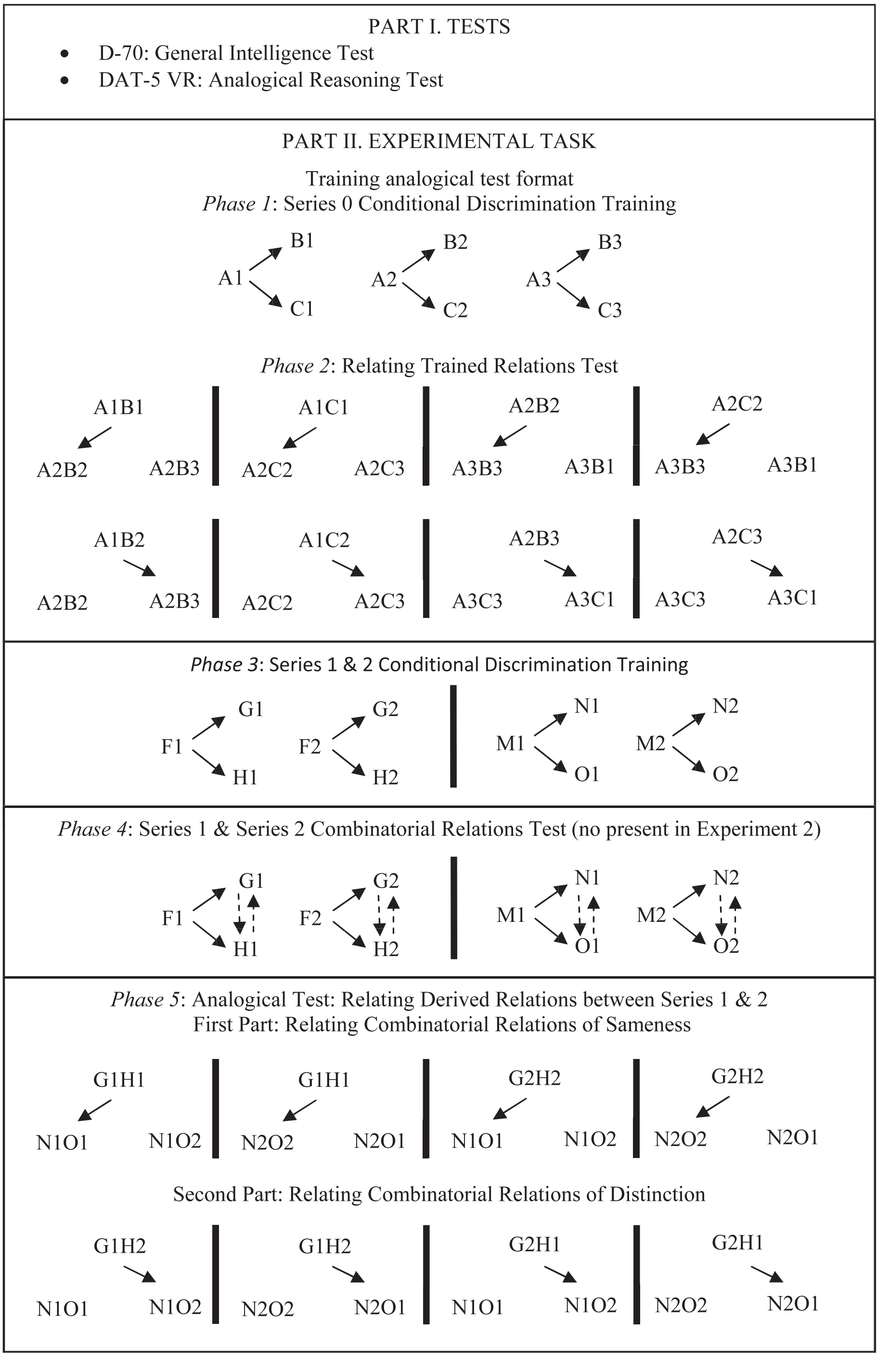

Fig. 1. Overview of Experiments 1 and 2 procedures.

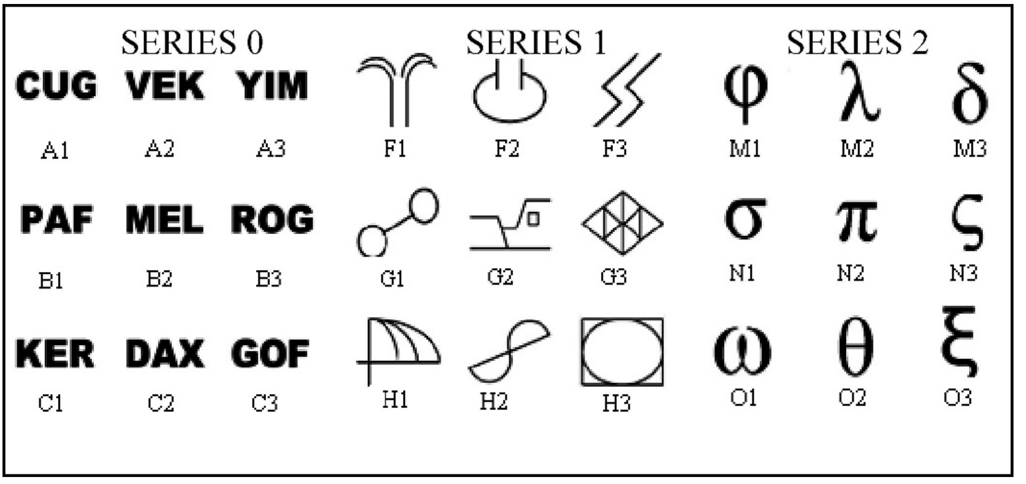

Fig. 2. Arbitrary stimuli used in Experiments 1 and 2.

Verbal Reasoning Scale of the Second Level of the Differential Aptitude Test (DAT-5 VR; Bennet, Seashore, & Wasman, 1997). This is a 40-item analogical reasoning test in which participants are given five options to complete the *a* and *d* terms of classic analogies (i.e., *a* is to *b* as *c* is to *d*; for example: ''… is to tree as spring is to …'' given the options earth-source, fruit-stone, grass-snow, stem-river, fertilize-source). We used the Spanish adaptation by TEA Ediciones, which reported Cronbach's alphas between .77 and .83 and has been used to successfully predict academic performance. The mean score found for university students was 22.09 (SD = 6.62).

Procedure

Upon arriving at the laboratory, participants were told that the experiment had two parts: one consisting of completing two tests (Part I) and another one consisting of a computer task (Part II). The complete experiment lasted between 95 and 130 min and participants were run individually. Participants were given the option to complete the experiment on that day or in two consecutive days. Those who chose to complete the experiment in the same day were asked to reconfirm their choice before beginning the computer task.

Participants were escorted to the experimental room for the administration of the tests. They first responded to the D-70 and then to the DAT-5 VR. The experimenter applied both tests following their respective manual instructions and their administration took about 1 hr. Subsequently, the computer task began (see Figure 1), which lasted 50 min, on average. It consisted of the five phases that are described below.

Phase 1: Series 0 Conditional Discrimination Training. The following instructions were presented on the screen at the start of this phase:

1. A figure will appear at the top of the screen.
2. Then, three figures will appear at the bottom of the screen.
3. Your task is to click with the mouse on the bottom figure that goes with the upper figure.
4. The computer will tell you if your response is right or wrong.
5. Mistakes are normal at the beginning.
6. Your task is to get as many correct responses as possible.

Participants underwent training on six different conditional discriminations (A1B1, A1C1, A2B2, A2C2, A3B3, and A3C3) using a simultaneous matching-to-sample procedure (Sidman & Tailby, 1982). Training trials were as follows: a sample (e.g., A1) appeared in the center of the upper third of the screen. One second later, three comparisons (e.g., B1, B2, B3) appeared in line horizontally in the lower third of the screen. Participants responded by clicking on one of the comparisons with the mouse. Immediately after responding, all the stimuli were removed from the screen. Correct responding (i.e., B1) was followed by the word ''CORRECTO'' (i.e., correct) in capital letters and white color, centered on the screen. Incorrect responses were followed by the word ''MAL'' (i.e., wrong). Feedback remained on the screen for 2 s, after which the screen became blank for another 2 s and a new training trial followed.

The training sequence for participants 1–9 was as follows. First, A1B1 was trained until the participant emitted two consecutive correct responses. Then, the same criterion was applied to A2B2 and A3B3. Subsequently, blocks of six trials (two trials per each A–B relation) were randomly presented until participants produced one block with 100% correct responses. The remaining new relations were trained in the same manner, except for the order of training (in this case, first A2C2, then A3C3 and, finally, A1C1). After achieving the criterion in the mixed block of A–C training, six-trial blocks with A–B and A–C relations (one trial per relation) were presented until two consecutive blocks with 100% correct responses were produced. Then, a written message appeared on the screen that informed participants that no feedback would appear during the next trials and two 6-trial blocks (one trial per each A–B and A–C relation) started. If a participant produced 100% correct responses in both blocks, the next phase commenced; otherwise, the same two 6-trial blocks were presented with feedback as a retraining.

Participants 10–12 received a more sequential and errorless-based discrimination training (Terrace, 1963) because participants 1–9 had difficulty passing the mixed blocks on the first attempt. The new sequence was as follows. Training of one relation (e.g., A1B1) proceeded until achieving the same criterion as above (i.e., two consecutive correct responses). Then, a new relation was trained (e.g., A2B2) followed by a four-trial block of the two relations (two trials per relation), until achieving 100% correct responses. Next, A3B3 and A2C2 were trained in the same way and were followed by a mixed-type block with these two relations. Subsequently, two 4-trial, mixed-type blocks containing all the four previous relations (i.e., A1B1, A2B2, A3B3, A2C2) were presented. When participants responded correctly to two consecutive blocks, A3C3 and A1C1 were trained in the same way (i.e., first separately and then in a 4-trial mixed type block). Finally, several consecutive mixed-type blocks followed until participants responded correctly to two of each one: (a) four-trial blocks with A3B3, A1C1, A2C2 and A3C3; (b) four-trial blocks with A1B1, A2B2, A1C1 and A3C3; and, finally, (c) six-trial blocks with the six trained relations. After a written message appeared informing participants that they would receive no feedback, training proceeded as indicated for participants 1–9.

Phase 2. Relating Trained Relations Test. The aim of this phase was to evaluate the discrimination of the relevant features of the analogical test format that would be conducted in Phase 5. This phase consisted of eight randomly presented trials: four similar–similar trials and four different–different trials. A typical trial was as follows: A compound stimulus with a previously trained relation (e.g., A1B1) was framed in a dark rectangle and appeared in the center of the upper third of the screen as a sample. One second later, two compound stimuli with other previously trained relations (e.g., A2B2 and A2B3), framed like the sample, appeared in a row in the lower third of the screen, one on the right and the other one on the left (positions changed randomly). Participants had to press the ''Z'' or the ''M'' keys to choose, respectively, the comparison on the left and on the right. If the sample stimulus was a trained relation of sameness (e.g., A1B1), then participants had to choose the trained relation of sameness (e.g., A2B2). The four trained similar–similar trials were (correct responses in italics): A1B1/*A2B2*, A2B3; A1C1/*A2C2*, A2C3; A2B2/*A3B3*, A3B1; A2C2/*A3B3*, A3B1 (see also Figure 1). If the sample compound stimulus was a trained relation of distinction (e.g., A1B2), then participants had to choose the trained relation of distinction (e.g., A2B3). The four trained different–different trials (correct responses in italics) were: A1B2/ A2B2, *A2B3*; A1C1/A2C2, *A2C3*; A2B3/A3C3, *A3C1*; A2C3/A3C3, *A3C1* (see Figure 1). The mastery criterion was to respond correctly to all eight trials.

The following instructions appeared on the screen at the beginning of this phase:

1. Two joint figures will appear at the top of the screen.
2. Then, two joint figures will appear at the bottom left of the screen and another two joint figures will appear at the bottom right of the screen.
3. Pay attention to both figures at the top.

4. Pay attention to both figures at the bottom left and to both figures at the bottom right.
5. Your goal is to select one of the two joint figures at the bottom of the screen that you think goes with the joint figures at the top. To choose the figures at the bottom left, press the "Z" key. To choose the figures at the bottom right, press the "M" key.
6. Your goal is to obtain as many corrects as possible, but…
7. THE COMPUTER WILL NOT SAY IF YOU ARE DOING WELL OR NOT.

Every incorrect response was followed by the presentation on the screen of the following instructions:

You are going to come back to the previous task. The computer will not tell you if your response is right or wrong. Please, pay attention to the screen in order to obtain as many corrects as possible.

Then, a retraining block of 12 trials (two trials of each relation trained in Phase 1; e.g., A1B1 relation) commenced as in Phase 1. However, in this case, if the participant responded to the trial correctly, the following simulation was shown: The two incorrect comparisons (e.g., B2 and B3) were removed from the screen and the sample and correct comparison stimuli (e.g., A1 and B1) moved towards the center of the screen and were framed into a dark rectangle to form a compound stimulus (e.g., A1B1). This process took about 7 s. If they responded correctly to all trials, they were reintroduced to the Relating Trained Relations Test. If participants responded incorrectly to one trial of this retraining block, all stimuli were removed from the screen and participants were exposed to further training with feedback as in Phase 1. Once they passed this block, they were returned to the block with movement feedback. No more than 10 attempts to pass the Relating Trained Relations Test were permitted.

Phase 3. Series 1 & 2 Conditional Discrimination Training. Stimuli from both Series 1 and 2 were used to form two separate 3-member equivalence classes: (Series 1: F1G1H1, F2G2H2; Series 2: M1N1O1, M2N2O2; see Figure 1). The training procedure was similar to the one conducted with Series 0 (i.e., errorless training with a 3-comparison matching-to-sample in which G3, H3, N3, and O3 were used as negative comparisons). First, participants underwent the training on the four relations from Series 1 (F1G1, F2G2, F1H1, F2H2), then the training on the four relations from Series 2 (M1N1, M2N2, M1O1, M2O2), and, finally, several mixed blocks were introduced.

The training sequence was as follows: Training of one relation (e.g., F1G1) proceeded until participants made two consecutive correct responses. Next, a new relation was trained (e.g., F2G2) in the same manner followed by a four-trial block with two trials per relation (i.e., F1G1 and F2G2) until achieving a block with 100% correct responses. This same rationale was repeated with the remaining relations of Series 1 (i.e., the F–H relations) but beginning the training with the relation F2H2 and following with F1H1. After the training of F–H was completed, four-trial blocks containing F–G and F–H relations (one trial per relation) were presented until two consecutive blocks with 100% correct responses were produced. A written message then appeared on the screen that informed participants that no feedback would appear upon responding during the next trials, and two 4-trial blocks without feedback started. If participants produced 100% correct responses in the two blocks, the conditional discrimination training of Series 2 began. Otherwise, they were retrained with 4-trial blocks (two F–G trials, two F–H trials) containing feedback until they responded correctly to two consecutive blocks. Then, blocks without feedback were presented as previously indicated.

Training of Series 2 involved four new conditional discriminations (M1N1, M2N2, M1O1, M2O2). The training sequence was as indicated for Series 1. The only difference was that the training of M–N relations began with M2N2 and the training of M–O relations began with M1O1. After the criterion was achieved with Series 2, the following blocks were introduced: (a) four-trial block with Series 1 (one trial per relation). Correct responding to the block was followed by (b) four-trial block with Series 2 (one trial per relation). Correct responding on the block was followed by a written message on the screen that informed participants that no feedback would be presented during the next trials, and (c) one mixed eight-trial block with the relations trained in Series 1 and Series 2 was introduced. Participants had to respond correctly to all trials in order to pass to the next phase; otherwise, the same eight-trial block with feedback was presented until they produced a block with 100% correct responses. Then, they returned to the eight-trial block without feedback.

Phase 4. Series 1 & 2 Combinatorial Relations Test. The aim of this phase was to evaluate the emergence of the combinatorial (or equivalence) relations of Series 1 and Series 2. Participants were presented with an eight-trial block with the same format used during training but without feedback. Each trial of this block evaluated a combinatorial relation of Series 1 (i.e., G1H1, H1G1, G2H2, or H2G2) or a combinatorial relation of Series 2 (i.e., N1O1, O1N1, N2O2, or O2N2). All the combinatorial relations were tested with the following rationale: the first stimulus of the relation appeared as a sample (e.g., G1) and the second stimulus of the relation appeared as a comparison with the other stimuli with the same assigned letter (e.g., H1, H2, and H3). As in Phase 3, Series 1 and Series 2 stimuli never appeared together on the same trial. The mastery criterion was 100% correct responses. Incorrect responding was followed by a 4-trial block of mutual (or symmetrical) relations (G1F1, G2F2, O1M1, O2M2). Responding correctly to all trials was followed by a new 8-trial block of combinatorial relations. If participants responded incorrectly to a mutual trial, further training of Series 1 and Series 2 was reintroduced as when responding incorrectly in Phase 3. Then, the mutual test was reintroduced and was followed by the combinatorial relations test. Participants who did not respond correctly to three combinatorial or to three mutual tests were dropped from further participation.

Phase 5. Analogical Test: Relating Combinatorial Relations between Series 1 and Series 2. The question asked was: Would participants relate combinatorial relations of sameness and distinction from the two separate stimulus series? The trial format contained two parts, as in Phase 2.

First part: Relating Combinatorial Relations of Sameness. Four similar–similar trials were presented. The sample was always a compound stimulus with a combinatorial relation of sameness from Series 1 (e.g., G1H1) and the comparisons were two compound stimuli from Series 2: one combinatorial relation of sameness (e.g., N1O1) and a combinatorial relation of distinction (e.g., N1O2). Participants were required to respond by pressing the key corresponding to the combinatorial relation of sameness from series 2 in each trial. These trials were (see also Figure 1): G1H1/*N1O1*, N1O2; G1H1/*N2O2*, N2O1; G2H2/*N1O1*, N1O2; G2H2/*N2O2*, N2O1. The mastery criterion to pass this part was to respond correctly to all four trials. If participants made a mistake, a retraining consisting of the full Phases 2 and 4, and the last blocks from Phases 1 and 3 followed completion of this part. In all cases, the mastery criteria and the consequences for incorrect responding were the same as in their respective phases. Specifically, the retraining sequence was: (a) Phase 1: One 12-trial block without feedback (2 trials per relation) of Series 0; (b) Phase 2: Relating Trained Relations Test; (c) Phase 3: One 8-trial block without feedback with each conditional discrimination of Series 1 and 2; (d) Phase 4: Series 1 & 2 Combinatorial Relations Test. When participants fulfilled the criterion, they returned to part 1 of the current phase. The maximum number of attempts allowed to pass the first part of the analogical test was three.

Second part: Relating Combinatorial Relations of Distinction. This consisted of four different–different trials that began immediately after participants fulfilled the mastery criterion for Part 1. No instructions were provided to the participants and, consequently, there was no division between this phase and the previous one. The sample consisted, in all cases, of a combinatorial relation of distinction from Series 1 (e.g., G1H2) and the comparisons were two compound stimuli from Series 2: a combinatorial relation of sameness (e.g., N1O1) and a combinatorial relation of distinction (e.g., N1O2). Participants were required to respond by pressing the key corresponding to the combinatorial relation of distinction of Series 2 in each trial. The trials were: G1H2/N1O1, *N1O2*; G1H2/N2O2, *N2O1*; G2H1/ N1O1, *N1O2*; G2H1/N2O2, *N2O1* (see also Figure 1). The criterion to pass this phase and to finish the experiment was to respond correctly to all trials. If participants made one mistake, they followed the same retraining indicated in the previous part of this phase. Likewise, participants were given only three opportunities for passing this part of the test. Upon completion of the test, participants were debriefed.

Table 1

Main results obtained in Experiment 1. Percentages of correct responses in Phases 1 and 3 refer to the whole phases.

N	Intelligence Tests		SERIES 0			SERIES 1 & 2				Phase 5. Analogical Test (Critical Test)	
			Phase 1		Phase 2	Phase 3		Phase 4			
	D-70	DAT-VR	Series 0 Training Trials	% Correct Series 0	Number Attempts Relating Trained Relations Test	Series 1&2 Trials	% Correct Series 1&2	Mutual Relations Test	Combi-natorial Relations Test	Part 1. Relating Relations of Sameness	Part 2. Relating Relations of Distinction
P10	35	33	113	92%	1	100	90%	–	8/8	4/4	4/4
P2	28	28	124	72%	2	92	90%	–	8/8	4/4	4/4
P7	–	25	57	86%	3	84	95%	–	8/8	4/4	4/4
P1	29	–	110	81%	4	96	91%	–	8/8	4/4	4/4
P4	26	26	170	71%	4	112	88%	–	8/8	4/4	4/4
P6	37	20	212	65%	6	92	91%	–	8/8	4/4	4/4
P3	34	27	132	78%	7	88	92%	–	8/8	4/4	1/3
			16	100%	1	8	100%	–	8/8	–	4/4
P8	27	21	198	73%	8	85	95%	–	8/8	4/4	1/4
			16	100%	1	8	100%	–	8/8	–	2/4
			16	100%	1	8	100%	–	8/8	–	4/4
P12	31	23	82	94%	7	92	90%	–	8/8	3/4	
			16	100%	1	8	100%	–	8/8	4/4	4/4
P9	32	23	168	84%	4	116	86%	–	0/1		
								4/4	4/5		
								4/4	8/8	3/4	–
			16%	100%	1	8	100%	–	8/8	4/4	4/4
P11	21	19	154	86%	8	115	91%	–	0/1		
								4/4	2/3		
								4/4	5/6		
P5	28	23	125	62%	10	–	–	–	–	–	–

Results

Intelligence Measures

Participant 1 could not complete the DAT-5 VR because his first language was not Spanish (he was able to complete the D-70 because it is a nonverbal test) and participant 7 could not complete the D-70 because of lack of time in the first session. Table 1 shows that the range of scores in the D-70 was 21–37 ($M = 29.82$, $SD = 4.57$) and 19–33 in the DAT-5 VR ($M = 24.36$, $SD = 4.03$). Both mean scores were midrange compared to the scores of Spanish university students (about 40th percentile in the D-70 and 60th percentile in the DAT-5 VR).

Series 0 Conditional Discrimination Training

All participants passed this training. Table 1 shows the number of trials to complete Series 0 training and percentage of correct responses in the whole phase. There were considerable differences in conditional discrimination training performance, ranging from 57 trials for P7 to 212 for P6. These differences did not correlate with any demographic variable or with D-70 nor DAT-5 VR scores. Participants who received the first training needed 144 trials and the percentage of correct responses was 74.66%, while participants who received the second training (i.e., the errorless training) needed 116.3 trials with 90.66% correct responses.

Relating Trained Relations Test

Table 1 shows that 11 out of 12 participants passed the Relating Trained Relations Test but only one on the first attempt. The remaining participants passed it after the retraining with movement as feedback. The mean number of attempts was 4.9. The number of attempts strongly correlated with the scores in the DAT-5 VR ($r = -.78$, $p = .008$) but not significantly with the D-70 scores ($r = -.28$, $p = .43$). Participants had statistically significantly more mistakes in the trained different–different trials ($M = 3$, $SD = 1.78$) than in the trained

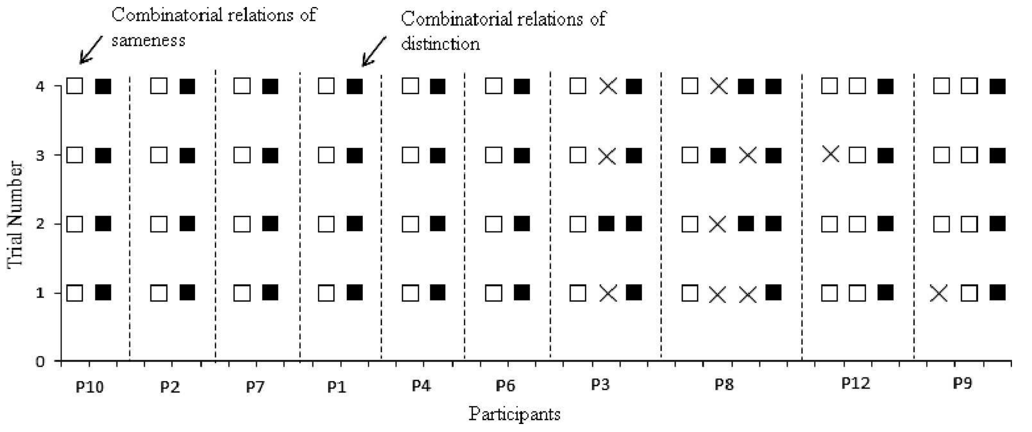

Fig. 3. Performance on each trial of the Analogical Test for individual participants in Experiment 1. Squares and crosses represent, respectively, correct and incorrect responses.

similar–similar trials (M = .91, SD = 1.37; Z = −2.42, p = .007).

Series 1 & 2 Conditional Discrimination Training

All participants completed the training of Series 1 and 2 conditional discriminations. There was less variability in the performance in this phase than in the Series 0 training, from 84 trials for P7 to 116 for P9 (see Table 1).

Series 1 & 2 Combinatorial Relations Test

Table 1 shows that 10 out of 11 participants passed this test (9 of them on the first attempt). Participant 11 was dismissed from the experiment since he did not pass the combinatorial test for series 1 and 2 within the five allowed attempts.

Analogical Test: Relating Derived Relations between Series 1 to Series 2

First Part: Relating Combinatorial Relations of Sameness. All 10 participants that arrived to the analogical test passed its first part. Specifically, 8 out of 10 participants passed this part on the first attempt while the other two passed it on the second attempt (P12 and P9).

Second Part: Relating Combinatorial Relations of Distinction. Again all participants passed this part: 8 out of 10 participants passed it on the first attempt, one participant on the second (P3) and the remaining one on the third (P8).

As can be seen in Figure 3, 6 out of 10 participants passed both parts of the analogical test on their first attempt (P1, P2, P4, P6, P7, and P10).

Discussion

All of the 10 participants who were given the Analogical Test eventually passed both parts of it. Therefore, this experiment is the first in which participants have showed the derivation of analogical relations between two separate relational networks (i.e., Series 1 and Series 2). Importantly, 6 of the 10 participants passed both parts of the test on the first attempt. The other main finding of this experiment is that participants' scores from the analogical reasoning test strongly correlated with the number of attempts that participants needed to pass the Relating Trained Relations Test. This result provides further data for the ecological validity of this behavioral empirical model of analogical reasoning.

A limitation of this experiment is that combinatorial relations of both relational networks were tested before the exposure to the Analogical Test. On one hand, these results could be interpreted in accordance with more basic behavioral processes. For instance, although no explicit feedback was provided on combinatorial trials, it could be argued that relating stimuli coherently with their history of relations might inherently provide reinforcement for most of the participants (e.g., Barnes-Holmes, Hayes, Dymond, & O'Hora, 2001; Luciano, Valdivia-Salas, Berens, Rodríguez, Mañas, & Ruiz, 2009; Törneke, 2010). If this were the case, the generativity of the participants' analogical performance would be reduced since they somehow would be relating trained relations rather than derived relations. Previous studies (e.g., Barnes et al., 1997; Carpentier et al., 2002, 2003) that have shown testing combinatorial relations facilitated the derivation of analogical relations seem to support this idea. On the other hand, the establishment of an analogy among two separate relational networks without a previous evaluation of their combinatorial relations seems to be more in accordance with the use of analogies in everyday life and constitutes a better demonstration of the generativity of analogical reasoning. In everyday life, people do not necessarily have previously derived relations between the stimuli involved in the analogy but they actually derive those relations in the process of recognizing or producing the analogy.

Based on the previous points, the aim of Experiment 2 was to analyze if participants would recognize analogical relations between two separate relational networks on the first attempt without previously testing the combinatorial relations of each network. Experiment 2 used the same procedure as Experiment 1 with the exception that participants were not exposed to the Combinatorial Relations Test (Phase 4). In the case that participants did not pass the Analogical Test on the first attempt, a retraining including the Combinatorial Relations Test was implemented. An additional aim of Experiment 2 was to replicate the data concerning the correlation between the scores in the analogical reasoning test and the performance in the Relating Trained Relations Test.

EXPERIMENT 2

Method

Participants

Ten undergraduates from Universidad de Almería participated in this experiment (age range = 20–26 years; 6 females, 4 males). The recruitment of participants and their compensation for participation was the same as in Experiment 1.

Design and Variables

The design was identical to the one used in Experiment 1 with the exception of the absence of the Series 1 & 2 Combinatorial Relations Test before the first exposure to the Analogical Test (see Figure 1).

Settings, Instruments, and Stimuli

The experimental room, the visual stimuli and the instruments were the same as in Experiment 1.

Procedure

The procedure was the same as for participants 10–12 in Experiment 1, except that Phase 4 (Series 1 & 2 Combinatorial Relations Test) was eliminated. In other words, participants followed to the Analogical Test after passing the Series 1 & 2 Conditional Discrimination Training (see Figure 1). The retraining administered if a participant did not pass one part of Phase 5 was identical to Experiment 1 (i.e., included testing combinatorial relations). Therefore, participants in Experiment 2 were exposed to the Series 1 & 2 Combinatorial Relations Test only if they failed one part of Analogical Test.

Results

Intelligence Measures

Table 2 shows that the range of scores in the D-70 was 27–38 (M = 32.2, SD = 3.67) and 16 to 31 in the DAT-5 VR (M = 24.3; SD = 5.69). Both mean scores were midrange compared to the scores of Spanish university students (about 55th percentile in the D-70 and 60th percentile in the DAT-5 VR).

Series 0 Conditional Discrimination Training

Table 2 shows that all participants passed this training but with considerable differences regarding the number of trials needed (from 87 trials for P5 to 299 trials for P1; M = 141.9) and the percentage of correct responses produced in the whole phase (from 74% for P1 to 92% for P7; M = 85.5%). As in Experiment 1, these differences did not correlate with any demographic variable or with D-70 nor DAT-5 RV scores.

Relating Trained Relations Test

All 10 participants passed the Relating Trained Relations Test, 5 out of 10 on the first attempt and the remaining after the retraining with movement as feedback (M = 4.1 attempts; see Table 2). The number of

Table 2

Main results obtained in Experiment 2. Percentages of correct responses in Phases 1 and 3 refer to the whole phases.

N	Intelligence Tests: D-70	Intelligence Tests: DAT-VR	SERIES 0 Phase 1: Series 0 Training Trials	SERIES 0 Phase 1: % Correct Series 0	SERIES 0 Phase 2: Number Attempts Relating Trained Relations Test	SERIES 1 & 2 Phase 3: Trials Series 1&2	SERIES 1 & 2 Phase 3: % Correct Series 1&2	Only if Retraining: Combinatorial Relations Test	Phase 4. Analogical Test (Critical Test): Part 1. Relating Relations of Sameness	Phase 4. Analogical Test (Critical Test): Part 2. Relating Relations of Distinction
P6	38	29	88	91%	1	78	90%	–	4/4	4/4
P2	27	29	102	81%	1	93	92%	–	4/4	4/4
P5	34	25	87	94%	1	85	94%	–	4/4	4/4
P10	32	31	118	88%	1	84	93%	–	4/4	4/4
P8	31	28	136	93%	1	97	89%	–	4/4	4/4
P3	32	16	90	90%	6	87	90%	–	4/4	4/4
P7	32	18	111	92%	6	89	93%	–	4/4	4/4
P9	30	29	239	75%	6	93	92%	–	3/4	
			16	100%	1	8	100%	8/8	4/4	4/4
P1	38	20	299	74%	10	110	91%	–	3/4	
			16	100%	1	8	100%	8/8	3/4	
			16	100%	1	8	100%	8/8	4/4	4/4
P4	28	18	149	77%	8	89	93%	–	2/4	
			16	100%	1	8	100%	8/8	4/4	3/4
			16	100%	1	8	100%	8/8	–	4/4

attempts needed to pass the test strongly correlated with the scores in the DAT-5 VR ($r = -.74$; $p = .014$) but were not correlated with the D-70 ($r = .09$). There were no statistically significant differences between the number of errors in trained different–different trials ($M = 2$, $SD = 2.36$) and trained similar–similar trials ($M = .7$, $SD = 1.59$; $Z = -1.63$; $p = .1$), although there were more of the former.

Series 1 & 2 Conditional Discrimination Training

Table 2 shows that all participants completed the training of Series 1 and 2. There was less variability in this training than in Series 0 training, from 78 trials (P6) to 110 trials (P1) and between 89% (P8) and 94% (P5) of correct responses.

Analogical Test: Relating Combinatorial Relations between Series 1 to Series 2

First part: Relating Combinatorial Relations of Sameness. All 10 participants passed this part of the test (see Table 2). Specifically, 7 out of 10 participants passed this test on the first attempt. The remaining 3 participants passed this part after being retrained and tested for combinatorial relations of Series 1 and 2. Two participants passed it on the second attempt (P9 and P4) and 1 participant on the third attempt (P1).

Second part: Relating Combinatorial Relations of Distinction. Table 2 shows that 9 out of 10 participants passed this part of the test on the first attempt and 1 participant (P4) passed it on the second attempt.

As can be seen in Figure 4, 7 out of 10 participants responded correctly to both parts of the Analogical Test on the first attempt (P2, P3, P5, P6, P7, P8, and P10).

Series 1 & 2 Combinatorial Relations Test

Only the 3 participants who did not pass a part of the analogical test on the first attempt were exposed to the Combinatorial Relations Test (P1, P4, and P9). All of them passed it on the first attempt (see Table 2).

Discussion

All 10 participants eventually passed both parts of the Analogical Test. Importantly, 7 of the 10 participants passed the test on the first attempt so that they were not exposed to the Series 1 and 2 Combinatorial Relations Test. The main contribution of this experiment is the demonstration of the recognition of cross-domain analogies on the first attempt without

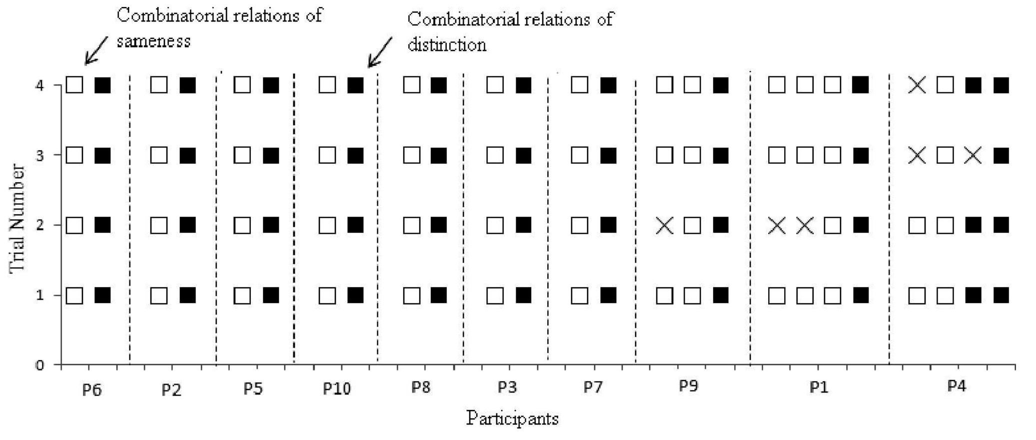

Fig. 4. Performance on each trial of the Analogical Test for individual participants in Experiment 2. Squares and crosses represent, respectively, correct and incorrect responses.

the previous testing of combinatorial relations of each relational network. As in Experiment 1, we found a very strong correlation between the number of attempts needed to pass the Relating Trained Relations Test and the score in the analogical reasoning test (DAT-5 VR).

GENERAL DISCUSSION

Participants in both experiments related derived relations among two separate relational networks. Specifically, in Experiment 1, 6 out of 10 participants showed this type of derivation on the first exposure to the Analogical Test after testing the combinatorial relations of both networks. This previous testing was the main limitation of Experiment 1 because it reduced the generativity of the participants' analogical performance and the results may be interpreted based on more basic behavioral processes. Accordingly, Experiment 2 was conducted to overcome such limitations. The only difference between Experiments 1 and 2 was the elimination of the Combinatorial Relations Test before the first exposure to the Analogical Test. Importantly, 7 out of 10 participants passed the Analogical Test on the first attempt. Thus, this last experiment shows a relatively robust procedure for showing a clean and unargued derivation of cross-domain analogies. Additionally, the high rate of participants passing the Analogical Test on the first attempt (70%) supports the ecological validity of this model since people often establish analogies with apparent ease (e.g., Dunbar & Blanchette, 2001).

Interestingly, although previous research has shown that combinatorial relations testing facilitated the subsequent analogical responding (Barnes et al., 1997; Carpentier et al., 2002, 2003), the rate of participants passing the Analogical Test on the first attempt was roughly the same in both experiments of the current study. However, this result does not necessarily contradict previous research; the most sequential training of Series 0 (Phase 1), that was received by all participants in Experiment 2 and 3 participants in Experiment 1, seems to have facilitated correct responding on the first attempt to the Relating Trained Relations Test. Specifically, 0 of the 9 participants with the least sequential training and 6 of the 13 with the most sequential training passed the test on the first attempt. This errorless discrimination of analogical test features might be relevant for subsequent analogical performances.

Specifically, participants seem to have difficulties in discriminating the relation (sameness or distinction) between the stimuli that formed the compound stimuli in Phase 2 of this study and other related studies (e.g., Barnes et al., 1997; Barnes-Holmes et al., 2005). For facilitating this discrimination, the movement feedback was implemented after producing one mistake in the Relating Trained Relations Test. However, alternative aids might be implemented in further studies because movement feedback showed a limited effect, especially with the different–different trials. Although the greater difficulty in establishing different–different relations is consistent with previous studies (Barnes-Holmes et al., 2005), this result could also be due to a side effect of the movement feedback. Participants only received the movement feedback when they responded correctly to a trial (e.g., in the A1B1 trial participants saw how the sample, A1, and the correct response, B1, were joined on the center of the screen and framed as they appear in Phase 2). Consequently, participants were familiarized with compounds consisting of relations of sameness but not with compounds consisting of relations of distinction. Additionally, participants had an experimental history more focused on sameness relations. For instance, all sameness relations were trained and reinforced on multiple occasions, however, distinction relations were trained on fewer occasions and even some compound stimuli presented in the Relating Trained Relations Test contained derived and not trained relations of distinction (i.e., typically, participants did not produce an error with all conditional discrimination trials). An alternative and not mutually exclusive explanation, following Barnes-Holmes et al. (2005), is that relating relations of sameness (e.g., apple is to orange as dog is to cat) seems to be more frequent in natural language than relating relations of distinction (e.g., Luis is to his brother as chalk is to cheese).

Since an aim of this study was to analyze the relation between the performances in a standard analogical reasoning test and in the Relating Trained Relations Test, no more aids were added to movement feedback since they could eliminate the variability across participants. However, future studies may include training that could improve participants' discrimination of the trained relations between the stimuli that formed the compounds.

The very strong correlations found between the number of attempts needed to pass the Relating Trained Relations Test and the score in a standard measure of analogical reasoning (i.e., DAT-5 VR) strengthen the evidence about the external validity of this approach to analogical reasoning (e.g., Barnes-Holmes et al., 2005; Carpentier et al., 2002, 2003). Interestingly, no significant relation was found between the performance in the Relating Trained Relations Test and the score in the *g* factor test (i.e., D-70 test). This suggests that the performance in the Relating Trained Relations Test is specifically related to analogical reasoning abilities and seems to be functionally equivalent in view that they involve the discrimination of the relation established between one pair of stimuli and the selection of another pair that share the same type of relation. Although it would have been preferable to correlate the scores in the standard analogical reasoning test with the performance on a Relating Derived Relations Test (as in Phase 5), this was not compatible with our primary aim (i.e., to design a procedure that allows the derivation of analogical relations between separate relational networks on the first attempt). Further research may explore the last point and also the viability of designing a behavioral measure of analogical reasoning by adapting the procedure used in this study for testing purposes (e.g., adding a reliable measure of response latencies).

Some possible limitations of this study are worthy to note. First, a limitation that might be argued in the present study is that the two parts of the Analogical Test (i.e., Relating Combinatorial Relations of Sameness and Relating Combinatorial Relations of Distinction) appeared separately. It might be argued that, irrespective of the sample, participants only had to discriminate the similar–similar comparison in the Relating Combinatorial Relations of Sameness part and to discriminate the different–different comparison in the Relating Combinatorial Relations of Distinction. However, both parts of the tests were very brief and participants passed from one part of the test to the other one immediately, without receiving new instructions. Accordingly, participants who only followed the rule of selecting the combinatorial similar–similar comparison in the first part of the test would systematically fail in the first trial of the second part. This was not the case, however. For example, data from Experiment 2 strongly contradict this hypothesis since 9 out of 10 participants passed the second part of the Analogical Test on the first attempt and the one who failed this test on the first attempt responded incorrectly to its third trial.

It also might be argued that both parts of the Analogical Test were too short (only four trials each) and participants could pass the test by responding at random to the two comparisons of each trial. However, the probability of passing both parts of the test consecutively on the first attempt was only about 0.004%. Moreover, it is worth noting that presenting such brief tests and asking for a perfect percentage of correct responses precludes the possibility of learning to respond correctly throughout the test, although it was presented in extinction (as demonstrated in Pérez & García, 2008).

The current study has only focused on recognizing cross-domain analogies. Future research may compare the production and recognition of within-domain versus cross-domain analogies. Apparently, all things being equal, within-domain analogies are easier to recognize and to produce than cross-domain analogies as cognitive research suggests (e.g., Keane, 1987). Also, the present study has only analyzed purely verbal analogies (i.e., the relational networks only shared the same type of derived relations). However, analogies usually involve relating relational networks that share additional features other than the same type of trained or derived relations (e.g., Skinner, 1957; Stewart et al., 2001). Future studies should analyze the role of these common additional features in the derivation of analogies. For instance, the role of common physical properties across domains in the production of analogies has been largely studied within the cognitive approach (see Holyoak, 2005, for a review). However, the cognitive approach lacks a precise definition of analogy (e.g., Carpentier et al., 2004) and its research methods in humans are focused on tasks that do not control for the preexperimental history of the participants. Behavior analysis, especially Relational Frame Theory (RFT; Hayes, Barnes-Holmes, & Roche, 2001) in which most of the research on analogy has been conducted, is well positioned to begin a complete program of research on analogy that could isolate the contextual variables that are responsible for the development of this repertoire and play a relevant role in the use of analogy in specific applied settings.

In conclusion, this study is the first that shows the derivation of cross-domain analogies within this functional-analytic approach to analogical reasoning. This is relevant in view of the fact that cross-domain analogies have more generative potential (e.g., Gentner, 2003) and are of special interest in applied settings (e.g., Bassok & Holyoak, 1989; Blanchette & Dunbar, 2001; Dunbar & Blanchette, 2001). For instance, cross-domain analogies have a relevant role in some forms of psychotherapy such as Acceptance and Commitment Therapy (ACT; Hayes et al., 1999). In order to facilitate a client into realizing the consequences of his or her actions, the ACT therapist often establishes analogies between what the client is doing to resolve a problem and another previously unrelated area (e.g., trying to control anxiety is like struggling in quicksand: the more you struggle, the faster you sink).

Finally, this study strongly supports this approach by contributing data concerning its external validity (responding to a four-term analogy task seems to be functionally equivalent to responding to the experimental Analogical Test) and ecological validity (most participants passed the Analogical Test on the first attempt).

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