Individual Differences in Transfer Mediated by Conceptual Priming

Jairo Navarrete (jnavarrete@ubiobio.cl)
Departamento de Ciencias Básicas, Universidad del Bío-Bío
Avda. Andrés Bello 720, Chillán, Chile

Abstract

Research in analogical transfer suggests a simple type of transfer that occurs due to the activation of key relational concepts. Analysis on mental structured representations indicates that this transfer may act differently depending upon structural and perceptual features of the priming task. Two hundred eight participants were assigned to three experimental groups where they received a structure-priming, tested once and afterwards they received a perceptual-priming and tested again. As predicted, the effect of structure-priming was found across conditions whereas the effect of perceptual-priming (a six-second animation) was detected only in subjects with high levels of cognitive reflectiveness. These individual differences are interpreted as evidence that only highly reflective subjects were able to process visuospatial cues in the animation and to extract their structural features, hence activating relational concepts that influenced their interpretations of subsequent tasks.

Keywords: Analogy, transfer, priming, cognitive reflection.

Introduction

In the fields of problem solving and analogy research, certain transfer effects have been linked to the low level cognitive process of priming. In one study, subjects were confronted with a biochemistry problem and learned that an inhibitory enzyme decreased virus reproduction (Schunn & Dunbar, 1996). The next day, the same subjects confronted a genetics problem involving the concept of an inhibitory gene. Although the two problems were not analogous, subjects exposed to the key concept of inhibition in the first session were more likely than control subjects to develop a solution based on the concept of inhibition for the transfer problem. Similarly, Day and Goldstone (2011) showed that subjects familiarized with a simulated physical system of motion were able to transfer the notion of "oscillatory motion" to interpret transfer tasks posed in a context of urban planning. This transfer arises not from a systematic mapping from source to target, but it is due to the activation of one or more key concepts (i.e. priming) and thus it has been called a "piecemeal transfer" (Holyoak, 2012, p. 246).

Similar effects were observed by Burns (1996) when researching transfer between episodes of analogical reasoning. The experimental tasks involved four-term letter-string analogies such as the one depicted in Figure 1. Burns had participants justify a given answer to a first analogy prior to having them propose solutions to a second (non-analogous) one. Half of the subjects had the two analogical problems presented in the reversed order, and the differences between the two groups on the relative frequencies of all defensible solutions suggest order effects that are consistent with the hypothesis that concepts activated during the first episode effectively biased the solution strategies followed by participants during the second episode. Burns explained these order effects as the formation of analogical mappings during the first analogical episode which afterwards are transferred to the second analogical episode.

abc : abd :: xyz : ???

Figure 1: This analogical problem can be stated as "if you changed abc to abd, how would you change xyz in the same way?"

However, Burns' theoretical explanation cannot account for the "piecemeal transfer" observed in the aforementioned studies because the referred problems are not analogical episodes: Within the biochemistry problem, there are no analogical mappings that can be transferred to the genetics problem. Similarly, no analogical mappings in the physical system can be transferred to the domain of urban planning. Hence, this study adopts the view that the activation of key concepts (i.e. priming) helps subjects to spontaneously interpret subsequent tasks according to the primed concept. The research presented here contributes by identifying differences among two kinds of priming referred here as *structural priming* and *perceptual priming*. The former being akin to the effect documented by Burns whereas the latter more akin to the one observed by Day & Goldstone.

A proper outline of the method and predictions for this study requires an analysis of the mental representations underlying tasks such as the one in Figure 1. The next section provides such analysis and proposes mechanisms by which priming may affect the interpretation of these tasks.

Representations of Four-term Analogies

Four term analogy problems have the form A : B :: C : ? where A and B comprise the source of the analogy whilst C along with the unknown constitute the target of the analogy. To solve this problem, one must interpret the source domain and then look for a solution D such that the relations between A and B can be mapped to the relations between C and D. This kind of problems promote the identification of the source's structure (Indurkhya, 1989) and thus they will be used in the present study to induce structural priming.

Additionally, these tasks will be used here as a manner to measure the priming effect by assessing the interpretation given to the source domain when solving these problems. This is possible because four term analogies in letter-strings (see Figure 2) can be represented by propositions (Burns, 1996). For example, the "append" concept may be represented by the *schema* "+" in a way that "+(ab, cd)" represents "abcd". And certain notion of reflection can be represented by the schema "mirror" so that "mirror(xyzw)" becomes a representation of "wzyx".

Relational schemas (such as the ones mentioned above) play an important role in cognitive research because there is evidence that they allow encoding structural knowledge as a combination of schemas and primitive elements (Halford, Bain, Maybery, & Andrews, 1998). For example, the string "aab12aab" can be seen as emerging from two primitive elements, namely "aab" and "12". And the source domain of the problem in Figure 2 (i.e. the first two terms) can be represented as it is depicted at the top of Figure 3. In such case, dominant theories of analogical mapping (Gentner, 1983; Holyoak & Thagard, 1989) predict that **"cde12edc"** would be the response to this analogical problem.

aab12aab : aab12baa :: cde12cde : ????????

Figure 2: An ambiguous four term analogy problem

However, the structure depicted in Figure 3 is not the only one that fits the problem, since the base analog could be alternatively conceptualized by a "shift" schema, namely an operation that takes the last letter and moves it to the first position (e.g. shift(xyzw) = wxyz). Although shift and mirror schemas represent different concepts, they sometimes cannot be differentiated from their action on one particular instance. As an illustration, notice that

mirror(aab) = shift(aab) = baa.

This makes the analogy in Figure 2 an ambiguous problem: replacing all the "mirror" occurrences in Figure 3 by "shift" leads to another structured representation which predicts a different answer, namely **"cde12ecd"**. This provides a basis to detect the priming effect by assessing the interpretation used by subjects in resolving the problem: if they conceptualized it through the mirror schema, they would prefer "cde12edc" as an answer, whereas if they used the shift schema, they would rather prefer "cde12ecd".

The present study tests the hypothesis that tasks requiring the generation of structured representations can prime a schema in a different manner than those tasks that do not require such structured representations. Several studies from analogical transfer research emphasize differences between abstract, structural aspects of an episode and its perceptual, concrete aspects. The evidence indicates that both aspects influence analogical transfer but that structural aspects have a greater impact than perceptual ones (Blanchette & Dunbar, 2000; Holyoak & Koh, 1987). Structural and perceptual features of a priming task may influence transfer as follows: a structure-based task (e.g. the one in Figure 2) might force subjects to create structured representations, thus activating the involved relational schemas. In contrast, a perception-based task (e.g. describing a dynamic visual stimulus) may evoke structured representations only in specific individuals, thus leaving open the possibility that schemas remain deactivated while performing the task. More precisely, these individuals may extract structural features from visuospatial cues in the perception-based tasks thus activating relational schemas that influence their interpretations of subsequent tasks. To address for this possibility, the cognitive reflection test (CRT, Frederick, 2005) was taken into account because research in decision making has shown that people who score highly on this test are more likely to engage in rational, analytic thinking (Shah, Michal, Ibrahim, Rhodes, & Rodriguez, 2017) whereas subjects with lower scores are less sensitive to notice abstract aspects of a task (Toplak, West, & Stanovich, 2011).

+(aab +(12, aab)) : +(aab +(12, mirror(aab))

+(cde +(12, cde)) : +(cde +(12, mirror(cde))

Figure 3: (Top) The domain "aab12aab : aab12baa" is represented as a combination of schemas—"append" and "mirror"—and primitive elements—"aab" and "12". (Bottom) The answer "cde12edc" for the problem in Figure 2 results from applying the same combination of schemas to the target domain by mapping primitive elements.

Summarizing, structural-tasks should force the generation of structured representations, meaning that the effect of this structural-priming on interpreting a subsequent episode is independent of participant's cognitive reflection. In contrast, perceptual-tasks may evoke structured representations only in subjects with high cognitive reflectiveness, meaning that the effect of perceptual-priming on interpreting subsequent episodes is expected to be effectively modulated by participant's cognitive reflection.

Method

Participants

An initial sample of 231 undergraduate students at a Chilean university (Age range 19-29 years, M = 20.6 SD = 2.1) participated in the study for course credits. They were randomly assigned to one of three conditions: two priming conditions and one control condition.

Procedure and Design

Subjects in the "first mirror then shift" condition (M-S) received a structure-priming favoring a "mirror" schema and were presented with a first test. Afterwards they received a perceptual-priming favoring the "shift" schema and were presented with a second test. Similarly, subjects in the "first shift then mirror" condition (S-M) received a structure-priming favoring the "shift" schema and were presented with the first test. Afterwards they received a perceptual-priming favoring the "mirror" schema and were presented with the second test. This design (detailed below) permits assessing the desired effect of priming on interpreting a transfer episode as follows: the effect of structure-priming can be assessed by comparing the experimental groups in terms of the scores collected in the first test. The effect of perceptual-priming will be assessed through comparing *the change of scores* (from the first test to the second test) experienced by each experimental group. The no-priming condition (NP) was taken as a control condition: subjects in this condition were primed to activate different schemas than the mirror and shift ones.

The experiment was administered in small groups at the computer laboratory of the university, with each participant working individually at her own pace. Participants took between 15-20 min (M = 17.6; SD = 4.6) to complete the experiment. The *Qualtrics* online platform was used to build a questionnaire comprising the following phases: (1) Introduction, (2) Structure priming, (3) Test 1, (4) Cognitive Reflection Test, (5) Perceptual priming, (6) Test 2 and (7) Test 3 (a hinted repetition of Test 2). As noted above, the between-subjects manipulation was restricted to phases 2 and 5; the other phases were identical across conditions. A detailed description of each phase is provided now.

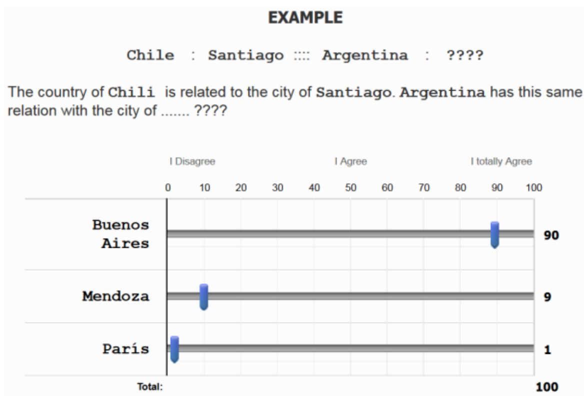

Figure 4: Display for the acquisition of preference scores.

Introduction: In order to familiarize participants with 4-term analogies, the computer screen presented the analogy “Chile:Santiago::Argentina:???”, along with its meaning i.e. “Chile is related to Santiago in the same way that Argentina is related to which city?”. Three alternative answers were given (Buenos Aires, Mendoza and Paris) each one coupled with a sliding bar ranging from 1 to 100 (see Figure 4). A text below explained that the three scores must add up to 100, and that they should reflect how good each answer seemed to be. The options were preset at scores of 90, 9 and 1, respectively, with an accompanying text stating that while Mendoza might be a plausible answer (score of 9) because the fact that it belongs to Argentina parallels the fact that Santiago belongs to Chile, a much better answer should be Buenos Aires (score of 90), because its being the capital of Argentina matches the "capital of" relation that holds between Santiago and Chile. Finally, the instructional text stated that Paris is not a good answer (score of 1) because it is hard to find a relation between Paris and Argentina that parallels some relation between Santiago and Chile.

Structure-priming: This phase was intended to activate particular schemas in participants' minds through a priming method similar to the one presented in Burns (1996). Participants in the M-S condition received the **mno678 : onm876 :: def234 : ???** problem. According to my analysis, this problem allows only one acceptable solution that involves projecting onto the rightward term of the analogy the mirroring operations that transform the base structures “mno” and “678” into “onm” and “876”, respectively. The above transformations could only be conceptualized in terms of mirroring operations, and thus it was expected participants to massively assign high scores to **fed432** (derivable via mirroring) and low scores to both edf324 and 4def23 (not derivable via such operation). This should lead to an increased activation of the mirror-schema in relation to other possible transformations. Participants in the S-M condition received the **mno678: omn867 :: def234 : ???** problem, an analogy whose only acceptable solution involved applying the "shift" operation that transform the base structures “mno” and “678” into “omn” and “867”, respectively. We expected participants in this group to assign high scores to **fde423**, and low scores to both edf324 and 4def23 alternatives. Participants in the NP condition received the **human:lungs::fish:???** analogy, followed by the alternatives "gills", "spine" and "fins". Given that this analogy should be solved by evoking the relation "X breathes through Y", we expected this control condition to prime neither a mirroring nor a shifting operation. In these and all subsequent analogical problems, three competing solutions were presented in random order, with their corresponding sliding bars preset to one.

Test 1 To assess whether the structure-priming received in the previous phase can bias subsequent processing, participants of all conditions received the ambiguous problem **aab12aab : baa12baa :: cde12cde : ???.** This analogy is solvable by applying either mirroring or shifting operations (options edc12edc and ecd12ecd, respectively). The remaining option (dec12dec) could not be derived from the leftward term of the analogy, and thus was expected to receive low scores regardless of condition.

Cognitive Reflection Test (CRT) This stage was presented to participants as a problem solving section. It comprised three algebra problems whose correct solution does not require complex calculations, but requires participants to suppress an "impulsive" solution that easily comes to mind[1]. As an example, the first item of the CRT consisted of the following problem: "A bat and a ball cost $1.10. The bat costs $1.00 more than the ball. How much does the ball cost?" Participants had no time limit to answer the problems. No particular criterion was taken into account in order to place the CRT here (between the two main measurement stages). After completing the third item, a yes/no question queried participants about whether they were familiar with any of the problems prior to the experimental session.

Perceptual priming: After being presented with a web video player, participants were asked to run a (six seconds)

[1] CRT is correlated with cognitive ability (Frederick, 2005; Toplak, West, & Stanovich, 2011), but can still predict rational thinking and performance on heuristics and biases tasks after controlling for the variance associated with assessments of intelligence, thinking dispositions, executive functions and cognitive skills. Thus, people who score highly on the CRT can be categorized as being more likely to engage in rational, analytic thinking (Shah, Michal, Ibrahim, Rhodes, & Rodriguez, 2017).

video animation. They were told that they would be able to watch the animation just once, and that they should pay careful attention in order to answer one brief question about the animation (answer limited to 200 characters). This question was aimed to provide a control mechanism to assess whether participants attended to the animation. Depending on the condition, the animation displayed a geometrical array whose dynamic movement was either compatible with a mirroring operation (S-M), with a shift operation (M-S) or unrelated to both (NP).

For the S-M condition, the animation showed how a transparent panel containing three horizontally arranged card figures performed a 180º turn along the middle vertical axis[2]. As the left-to-right order of the figures changed from "club, diamond, heart" to "heart, diamond, club", this animation was a visuospatial representation of the "mirror" operation. Participants were asked about how the spatial configuration of the club changed during the animation.

For the M-S condition, the animation showed a hammer imparting a rightward motion to the leftmost of three horizontally arranged geometrical figures; this rightward motion was transmitted to the middle figure and ultimately transmitted to the rightmost figure, making it slide-off through a circular circuit that ended up relocating it in the leftmost position[3]. As the left-to-right order of the figures changed from "circle, square, rhombus" to "rhombus, circle, square", this animation was intended to convey a visuospatial representation of the "shift" operation. Participants were asked about how the spatial configuration of the rhombus changed during the animation.

For the NP condition, the animation displayed a transparent rectangle containing three horizontally-arranged card figures (club, diamond and heart) which performed a 360º turn along its middle horizontal axis, thus leaving the left-to-right ordering of the figures unchanged[4]. As this rotational movement was unrelated to either the mirror or shift operations, it was intended to avoid the activation of the mental representations associated to the two crucial operations. Subjects were asked how the spatial configuration of the club changed during the animation.

Test 2 To assess whether the visuospatial animations received during the previous phase altered subsequent processing, participants of all conditions received the ambiguous problem **pq89pq : qp89qp :: xyz89xyz : ???.** According to our analysis, this analogy is solvable by applying either mirroring or shifting operations (options zyx89zyx and zxy89zxy, respectively). As in Test 1, the remaining option (xyz89xyz) could not be derived from the leftward term of the analogy, and thus was expected to receive low scores regardless of condition. Upon assigning scores to each of the presented alternatives, subjects were asked to answer a yes/no question about whether the watched video had spontaneously popped up into their minds while reading the analogy and/or evaluating the presented alternatives.

Test 3 This is a control measure aimed to assess the extent to which participants were *potentially* able to use the information contained in the animation for solving the problem presented in Test 2. Participants received the analogy and the same solution options as in Test 2, but it was preceded by an explicit hint, namely, to take into account the animation for assigning scores to the presented alternatives.

Data Analysis

Participants were classified as having low cognitive reflection if their CRT score was equal to zero, and as having high cognitive reflection in the other cases. Since this study is based on priming effects, I discarded data from 23 participants (4 in the M-S condition and 19 in the S-M condition) who failed to assign high scores (>= 80) to the only defensible solution to the unambiguous problem of phase 2, which was meant to operate as a structure-priming for the following phase. A preliminary analysis of the data revealed that a non-negligible proportion of participants in the control condition assigned high scores to the "incorrect" solution for the ambiguous problem presented during Test 1, thus lessening preferences for the meaningful alternatives. To prevent this unanticipated behavior of the NP group from engendering spurious correlations, raw preference scores were converted to normalized scores which reflect the proportion of preference assigned to the mirror-alternative in relation to the total amount of preference assigned to the two competing and meaningful alternatives:

$$NSPM = 100 * \frac{P_m}{P_m + P_s}$$

As an example, if a subject assigned a preference of 10 to the mirror-alternative, 40 to the shift-alternative and 50 to the incorrect alternative, its NSPM would be 20%, reflecting that one fifth of the total amount of (the relevant) preference was assigned to the mirror-alternative whereas the remaining 80% was assigned to the shift-alternative. Due to the ratio form of NSPM scores[5], I report geometric means (GM) obtained by computing arithmetic means on the logarithm of NSPM scores (see Table 1).

[2] See https://www.youtube.com/watch?v=n2gRewFVssY
[3] See https://www.youtube.com/watch?v=d56jnzPwBOU
[4] See https://www.youtube.com/watch?v=ALris6B4yj4

[5] A possible drawback of normalized scores (such as the NSPM) is that they are prone to overestimations. An extreme example can illustrate this situation: If a participant assigned a preference of 2 to the mirror-alternative and 1 to the shift-alternative, her NSPM score would be 66.6%, thus having a strong additive effect in computing averages, even though the mirror-alternative was ranked as negligible. This can be controlled by using geometric means: when a score is a ratio such as X_i/Y_i, the geometric mean is the *only* mean with the property $GM(X_i/Y_i) = GM(X_i)/GM(Y_i)$ i.e. it "normalizes" the ranges being averaged in such a way that no range dominates the weighting (Fleming & Wallace, 1986).

Table 1
NSPM scores at each stage of this study

		Log of NSPM scores						Geometric Means			GM Ratios	
		Test 1		Test 2		Test 3		Test 1	Test 2	Test 3	T2/T1	T3/T1
Condition	N	M	SD	M	SD	M	SD	GM	GM	GM		
Low CRT												
NP	34	3,52	1,59	3,82	1,48	3,45	1,57	32,8	44,6	30,5	1,36	0,93
M-S	47	4,01	1,15	4,24	0,71	2,5	2,15	54,1	68,4	11,2	1,26	0,21
S-M	32	3,23	1,66	3,12	1,89	3,54	1,83	24,3	21,6	33,5	0,89	1,38
High CRT												
NP	28	4,09	1,21	4,18	1,01	3,95	1,43	58,7	64,4	50,9	1,10	0,87
M-S	35	3,98	1,06	3,84	1,28	1,86	2,12	52,5	45,5	5,4	0,87	0,10
S-M	32	2,71	1,94	3,64	1,31	3,91	1,38	13,9	37,1	48,4	2,67	3,49

Table 1: The rows of the table report the (within-subjects) change of NSPM scores across the three measurement phases. The effect of structural priming is reported in the columns associated to Test 1. The column T2/T1 reports the ratio of geometric means associated to Test 1 and Test 2 and suggests a between-groups change of preferences detected only in subjects with higher levels of cognitive reflectiveness.

Results

Structure-priming A two-way ANOVA was conducted to examine the effect of condition (S-M, M-S and NP) and CRT level (low vs. high) on the NSPM scores collected during Test 1. Main effects emerged for condition $F(2, 203) = 10.09$, $\eta_p^2 = .085$, $p < .0001$. Cognitive reflection does not affect the interpretation of the problem in Test 1 since the main effect of cognitive reflection, $F(1,203) = .0001$, $\eta_p^2 = 0$, p = .99 and the interaction condition x cognitive reflection, $F(2,203) = 2.3$, $\eta_p^2 = .022$, $p = .10$ were not statistically significant. Planned comparisons confirmed differences on NSPM scores between the two competing conditions in each one of the two CRT levels. For high-CRT participants, the S-M condition produced significantly lower NSPM scores ($GM = 13.85$) than those of the M-S condition ($GM = 52.41$), $t(47.16) = 3.31$, $p = .0017$, $d = .58$. For low-CRT participants, the S-M condition produced significantly lower NSPM scores ($GM = 24.18$) than the M-S condition ($GM = 54.09$), $t(50.99) = 2.32$, $p = .024$, $d = .19$. As a base line for comparison, NSPM scores of subjects in the control condition (NP) are reported in Table 1. These results are consistent with those obtained by Burns (1996), and extend those findings by confirming that the effect of structural-priming on interpreting subsequent analogical tasks takes place regardless of whether participants exhibit (or not) a natural propensity to engage in rational, analytic thinking.

Perceptual-priming In order to detect possible small effects of perceptual priming, this experiment was designed to measure the extent to which a perceptual-priming can counteract the effect of a prior structure-priming. Therefore, participants whose structure-priming favored the mirror scheme later received a perceptual-priming favoring the shifting schema, and vice-versa. The eventual effect of perceptual-priming was assessed by analyzing the change of NSPM scores within subjects (from Test 1 to Test 2) i.e. the change of subject's appraisal for the mirror-compatible solution. To investigate this change of preferences at the level of individual participants, a 3x2x2 ANOVA was conducted with condition (S-M, M-S and NP) and cognitive reflection (High vs. Low) as between-subjects factors and session (Test 1 vs. Test 2) as a within-subjects factor. Main effects emerged for condition $F(2, 197) = 42.42$, $\eta_p^2 = .069$, $p < .0001$, but neither for cognitive reflection $F(1,197) = 0.32$, $\eta_p^2 < .001$, $p = .57$ nor for session $F(1,197) = 3.152$, $\eta_p^2 = .0011$, $p = .077$. As expected, the three-way interaction was significant $F(2, 197) = 3.06$, $\eta_p^2 = .017$, $p = .045$. To further understand this interaction, planned comparisons in each CRT-level were conducted. In the high-CRT group, the change of mirror-preferences was in agreement with the perceptual-priming: changes in the M-S condition (-7%) were significantly different from the change experienced in the S-M condition (23.2%), $t(63.36) = -2.63$, $p = .011$, $d = 0.644$. In contrast, the low-CRT group presented changes of mirror-preferences incompatible with the perceptual-priming: changes in the M-S condition (14.3%) were not significantly different from the changes in the S-M condition (-2.7%), $t(48.31) = .75$, $p = .46$, $d = .177$. Data in Table 1 suggests that the control group increased its appraisal for the mirror-alternative from Test 1 to Test 2, which indicates an inherent bias in the experimental design. Still, the results are consistent with the expectations: within participants with high reflectiveness, those who watched the visuospatial representation of the shift-scheme tended to lower their appraisal for the mirror-alternative and those who watched the visuospatial representation of the mirror-scheme increased their appraisal for the mirror-alternative. This is in line with the idea that participants with high reflectiveness were able to process the visuospatial priming-task and extract its relational features thus activating a schema that lessened the effect of the one activated in the previous structure-priming phase. In contrast, participants with low reflectiveness completed the visuospatial priming-task without noticing its structural features, thus not activating any schema and leaving "untouched" the effect of the schema activated in the structure-priming phase.

The differential effect of visuospatial representations between the two experimental groups was not due to the relative proportions of subjects consciously recalling the animations: A chi-squared test showed that the low-CRT and high-CRT groups had similar proportions of participants stating to recall the video while solving the analogy presented during Test 2 (21.5% vs. 28.3%, respectively), χ^2 (1, $N = 146$) = 0.58, $p = .45$. Only a minor proportion of participants spontaneously recalled the animation while solving the analogy in Test 2. This evidences that such stimuli have primed—rather than consciously induced—participants' appraisal of the mirror-alternative since a lack of conscious awareness represents a definitional feature of priming.

As cognitive reflection is correlated with general intellectual abilities (Frederick, 2005), an alternative interpretation for why participants with lower levels of cognitive reflection were not sensible to perceptual priming is that they are intrinsically less capable of translating the perceptual content of the animations to the more structured domain of letter-string problems. To assess this possibility, preferences on the two experimental groups was investigated when subjects were explicitly asked to recall the videos and use them into solving the analogy problem presented in Test 3 (same problem presented in Test 2). A two-way ANOVA was conducted to examine the effect of condition (S-M, M-S and NP) and cognitive reflection (low vs. high) on NSPM scores collected during Test 3. Main effects emerged for condition $F(2, 203) = 17.88$, $\eta_p^2 = .147$, $p < .0001$; but neither for cognitive reflection $F(1,203) = .08$, $\eta_p^2 = 0$, $p = .77$, nor for the condition x cognitive reflection interaction, $F(2,203) = 2.21$, $\eta_p^2 = .021$, $p = .11$. This confirms that the uneven effect of perceptual animations as a function of cognitive reflection did not originate in a higher intrinsic ability of the higher cognitive reflection group to understand the correspondences between the visuospatial animation and the subsequent analogical activity.

General Discussion

Theoretical analyses suggest a simple mechanism whereby transfer mediated by conceptual priming may occur, namely the activation of relational schemas—organized in structured representations—that influence the interpretation of subsequent tasks. The fact that analogical transfer is influenced both by structural and superficial features suggests that transfer mediated by priming should be also subjected to these two aspects: I expected differences of priming effects among tasks requiring structured representations and tasks requiring perceptual descriptions of visuospatial animations. The results confirm this hypothesis and link the disparity of effects to individual differences of subjects: structure-priming effects were found across conditions, whereas only those subjects with higher propensity to engage in analytical thinking were sensitive to perceptual-priming. These individual differences cannot be accounted for by group differences in neither the proportion of subjects consciously recalling the visual stimulus nor the ability to understand the correspondences between the visuospatial prime and the transfer task. Hence, the rationale is that highly reflective subjects unconsciously extract structural features from visuospatial cues thus activating relational schemas that influence their interpretations of subsequent tasks.

This seems to be consistent with certain evidence in literature. For example, students were asked to solve algebraic equations superimposed on a vertically oriented grating continuously moving either to the left or to the right (Goldstone, Landy, & Son, 2010). This was meant to investigate the effect of these background motions on the "spatial transposition strategy" e.g. moving the number 8 from the left to the right of the equality in 4*y+8 = 24. The study found that the compatibility of the background motion and the motion of numbers implicated by the spatial transposition strategy affects accuracy. The analysis and results presented here indicate that participants with higher propensity to engage in analytical thinking should be more affected by this compatibility because they are more likely to activate a motion-schema from the background motion which, depending on the condition, either conflicts or agrees with the "spatial transposition strategy". Interestingly, the aforementioned study reported that participants who have taken advanced courses of mathematics were indeed more affected by the compatibility between the two motions.

The results presented in this study are in line with claims in literature suggesting that deep structural aspects are more influential than perceptual-concrete aspects in achieving learning and transfer. But although these results must be viewed as preliminary given the specificity of this study's materials and scope, they open a question for further research: Can this general dichotomy between perceptual and structural aspects be linked to individual differences between subjects?

Acknowledgements

This research was supported by the Universidad del Bío-Bío grant 124009 3/D and FAPEI Fund. Thanks to Máximo Trench for constructive and helpful discussions. And thanks to various anonymous reviewers for useful comments.

References

Blanchette, I., & Dunbar, K. (2000). How analogies are generated: The roles of structural and superficial similarity. *Memory & Cognition*, *28*(1), 108–124.

Burns, B. D. (1996). Meta-analogical transfer: Transfer between episodes of analogical reasoning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(4), 1032.

Day, S. B., & Goldstone, R. L. (2011). Analogical transfer from a simulated physical system. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(3).

Fleming, P. J., & Wallace, J. J. (1986). How not to lie with statistics: the correct way to summarize benchmark results. *Communications of the ACM*, *29*(3), 218–221.

Frederick, S. (2005). Cognitive reflection and decision making. *The Journal of Economic Perspectives*, *19*(4), 25–42.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, *7*(2), 155–170.

Goldstone, R. L., Landy, D. H., & Son, J. Y. (2010). The Education of Perception. *Topics in Cognitive Science*, *2*(2), 265–284.

Halford, G. S., Bain, J. D., Maybery, M. T., & Andrews, G. (1998). Induction of relational schemas: Common processes in reasoning and complex learning. *Cognitive Psychology*, *35*(3), 201–245.

Holyoak, K. J. (2012). Analogy and relational reasoning. *The Oxford Handbook of Thinking and Reasoning*, 234–259.

Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer. *Memory & Cognition*, *15*(4), 332–340.

Holyoak, K. J., & Thagard, P. (1989). Analogical mapping by constraint satisfaction. *Cognitive Science*,*13*(3),295–355.

Indurkhya, B. (1989). Modes of Analogy (pp. 217–230). London, UK, UK: Springer-Verlag.

Schunn, C. D., & Dunbar, K. (1996). Priming, analogy, and awareness in complex reasoning. *Memory & Cognition*, *24*(3), 271–284.

Shah, P., Michal, A., Ibrahim, A., Rhodes, R., & Rodriguez, F. (2017). What Makes Everyday Scientific Reasoning So Challenging? In *Psychology of Learning and Motivation* (Vol. 66, pp. 251–299). Elsevier.

Toplak, M. E., West, R. F., & Stanovich, K. E. (2011). The Cognitive Reflection Test as a predictor of performance on heuristics-and-biases tasks. *Memory & Cognition*, *39*(7).