Psychonomic Bulletin & Review (2022) 29:1480–1491
https://doi.org/10.3758/s13423-022-02062-8

BRIEF REPORT

Differential effects of semantic distance, distractor salience, and relations in verbal analogy

Lara L. Jones[1] · Matthew J. Kmiecik[2,3] · Jessica L. Irwin[4] · Robert G. Morrison[5]

Accepted: 22 January 2022 / Published online: 7 February 2022
© The Psychonomic Society, Inc. 2022

Abstract

Prior studies of A:B::C:D verbal analogies have identified several factors that affect performance, including the semantic similarity between source and target domains (semantic distance), the semantic association between the C-term and incorrect answers (distracter salience), and the type of relations between word pairs. However, it is unclear how these stimulus properties affect performance when utilized together. To test their interactive effects, we created a verbal analogy stimulus set that factorially crossed these factors and presented participants with an analogical stem (A:B::C:?) with two response choices: an analogically correct (D) and incorrect distracter (D′) term. The semantic distance between source and target word pairs was manipulated creating near (BOWL:DISH::SPOON:SILVERWARE) and far (WRENCH:TOOL::SAD:MOOD) analogies. The salience of an incorrect distracter (D′) was manipulated using the sematic distance with the C-term creating low (DRAWER) and high (FORK) salience distracters. Causal, compositional, and categorical relations were presented across these conditions. Accuracies were higher for semantically near than far analogies and when distracter salience was low than high. Categorical relations yielded better performance than the causal and compositional relations. Moreover, a three-way interaction demonstrated that the effects of semantic distance and distracter salience had a greater impact on performance for compositional and causal relations than for the categorical ones. We theorize that causal and compositional analogies, given their less semantically constrained responses, require more inhibitory control than more constraining relations (e.g., categorical).

Keywords Verbal analogy · Semantic distance · Structure-mapping · Analogical relations

Verbal analogies of the form A:B::C:D entail comparison of conceptual relations between word pairs that are based on the meaning of the concepts. Solving such analogies entails several component processes (Sternberg, 1977; Sternberg & Nigro, 1980) including (1) relational inference from the source (A:B pair), (2) mapping between the corresponding elements of the pairs (A to C-term; B to D-term); (3) transfer of the inferred relation from the first pair onto the second (C:D) pair, and (4) response selection. Item factors such as word familiarity, semantic distance, and source-pair relation influence the difficulty of one or more of these processes and in turn the performance on an analogical task (Ichien et al., 2020). Within analogy, semantic distance represents the extent to which analogy terms differ in their underlying domains with "near" analogies having similar domains (SQUIRREL:RODENT::ROBIN:BIRD) and "far" analogies having different domains (WRENCH:TOOL::SAD:MOOD), with better performance for near than far analogies. Likewise, the number of distracting choices presented alongside the correct D-term, and/or greater semantic similarity between the distracter(s) and the C-term, can also impact performance (Morrison et al., 2004; Thibaut et al., 2010). Here we focus on "distracter salience" defined as the semantic distance between the C-term (ROBIN) with the analogically correct D-term (BIRD) compared with the incorrect D′-terms (NEST

✉ Lara L. Jones
larajones@wayne.edu

1 Department of Psychology, Wayne State University, 5057 Woodward Ave, Detroit, MI 48202, USA

2 Department of Obstetrics and Gynecology, NorthShore University HealthSystem, 2650 Ridge Ave. Suite 1507, Evanston, IL 60201, USA

3 Department of Obstetrics and Gynecology, Pritzker School of Medicine, The University of Chicago, 924 E. 57th Street, Chicago, IL 60637, USA

4 Department of Psychology, University of La Verne, 1950 Third Street, La Verne, CA 91750, USA

5 Department of Psychology, Loyola University Chicago, 1032 W. Sheridan Rd, Chicago, IL 60660, USA

Table 1 Example items

Semantic distance	Relation	A:B pair	C-term	D-term correct answer	High salient distracter	Low salience distracter
Near	Categorical	TARANTULA : SPIDER	BEE	INSECT	HIVE	YELLOW
	Causal	FRACTURE : CAST	INCISION	SCAR	SURGERY	STUMBLE
	Compositional	OATMEAL : COOKIE	BANANA	MUFFIN	PEEL	KIWI
Far	Categorical	WRENCH : TOOL	SAD	MOOD	HAPPY	LOSS
	Causal	INVITATION : VISIT	TORNADO	DESTRUCTION	WEATHER	PRAIRIE
	Compositional	FLOUR : TORTILLA	SILK	TIE	FABRIC	WORM

Note. The full set of items is available at https://osf.io/cd7b9

or BIRD; Morrison et al., 2004). As described herein, both semantic distance and distracter salience affect performance via the mapping and response selection processes.

Specific analogical relations, such as ROBIN is a *kind of* BIRD, may also impact performance (Ichien et al., 2020; Sternberg & Nigro, 1980). However, performance-related effects of semantic distance and distractor salience across different analogical relations has not been sufficiently investigated. A carefully controlled experiment is needed to examine whether (1) particular relations better facilitate the mapping and response selection processes over other relations and (2) the effects of semantic distance and distracter salience differ across relations. Hence, the purpose of our study was to investigate the separate and combined effects of all three factors—semantic distance, distracter salience, and relation type—on accuracies in a verbal analogy selection task. We discuss each of these factors in turn.

Semantic distance

Broadly, semantic distance refers to the path in a semantic network between nodes (Kumar et al., 2020). We adopt the definition commonly used within the context of verbal analogy, of semantic distance reflecting the similarity between the domains represented in the source and target word pairs (Green et al., 2006). For example, the pairs in the semantically near or same-domain analogy, BOWL:DISH::SPOON:SILVERWARE, both entail kitchen utensils, whereas in the far or between-domain analogy, WRENCH : TOOL :: SAD : MOOD, the source and target pairs are from different contexts. The greater similarity of domains in the near analogies facilitates one-to-one mapping (i.e., alignment of the corresponding A-C and B-D-terms). This process is known as *structural alignment* in the structure mapping theory (Gentner & Maravilla, 2018), and it is a fundamental part of the overall mapping process (see Gentner & Forbus, 2011, Table 1). That is, mapping between aligned terms in semantically near pairs (BOWL and SPOON) can be based on both semantic and structural similarity. In contrast, far analogies require more abstraction in the form of a greater reliance on structural similarity given the absence of semantic similarity (Green et al., 2014; Holyoak, 2012). Indeed, this greater semantic similarity between the corresponding terms in near analogies facilitates the structural alignment (Gentner, 1983; Gentner & Forbus, 2011; Gentner & Maravilla, 2018; Gentner & Smith, 2012; Hoyos & Gentner, 2017).

Near semantic distances are also a facilitative factor in projection-first models, which as demonstrated in many eye-tracking studies (Glady et al., 2016; Gordon & Moser, 2007; Thibaut & French, 2016; Thibaut, French, Missault, et al., 2011a; Vendetti et al., 2017), entail an initial focus on the A:B pair followed by more attention to the C-term and possible target pairs. In near analogies (e.g., BOWL:DISH::SPOON:SILVERWARE), the initial focus on the A:B pair would also activate any semantic or thematic information (e.g., kitchen or eating domain) in addition to the categorical relation. The relation and domain information would then be projected onto the C-term, which shares the same domain, to aid in the selection of the most suitable D-term.

Across a variety of verbal analogical tasks, performance was better for analogies having near than far semantic distance (Bunge et al., 2005; Green, 2016; Green et al., 2010, 2012; Green et al., 2014; Jones & Estes, 2015; Kmiecik et al., 2019; Vendetti et al., 2012; Vendetti et al., 2014; Weinberger et al., 2016). For example, in an analogical selection task that required participants to choose a response from five choices, response times (RTs) and accuracies were better for near than far analogies (Jones & Estes, 2015). These findings support the hypothesis that

greater semantic similarity between the source and target facilitates the structural alignment. Therefore, we predict a robust effect of semantic distance with higher accuracies for the semantically near than far analogies.

Distracter salience

Distracter salience refers to the relative semantic distance between the C-term and each answer option: the analogically correct D and incorrect distracter (D′) terms.[1] Distractor salience is high when the C-term of the analogy is semantically nearer to the distracter than the correct analogical answer. In LEATHER : SADDLE :: GOLD : EARRING, the C-term, GOLD, has a greater semantic similarity with the high salience distracter (SILVER) than with the correct answer (EARRING), but a lower semantic similarity with the low salience distracter (ALUMINUM) in comparison to the correct answer. Distracter salience is particularly relevant to the response selection component process in analogical selection tasks and may derail the mapping process. That is, one may have successfully mapped the A and C terms (e.g., LEATHER and GOLD) based on their relational roles as materials of their respective objects. Then GOLD would be mapped onto the to-be-selected D-term—an object that can be made of gold. However, in the process of selecting that D-term, the greater association between the C-term with a high salience distracter option (SILVER) may cause one to select this relationally inconsistent distracter rather than to complete the alignment of the B and D-terms. This derailment of the alignment is even more likely for those with less inhibitory control over salient responses, such as adults with frontal lobe injuries/disease (Krawczyk et al., 2008; Morrison et al., 2004) and children (Richland et al., 2006; Thibaut & French, 2016; Thibaut et al., 2010; Thibaut, French, Missault, et al., 2011a; Thibaut, French, Vezneva, et al., 2011b), and can also occur in young adults (Bugaiska & Thibaut, 2015).

In addition to predicting a main effect of distracter salience as found in prior studies (e.g., Bugaiska & Thibaut, 2015), we also predict an interaction with semantic distance. Given that mapping in near analogies is facilitated by both featural and relational/structural similarity, high distractor salience is more likely to impair performance on semantically far analogies given their reliance on relational roles (Gentner et al., 1993; Gentner & Kurtz, 2006; Rattermann & Gentner, 1998). Moreover, the type of analogical relation and its interaction with semantic distance and distracter salience may further impact performance.

Analogical relation

Analogies also vary in their semantic relation (Ichien et al., 2020; Jurgens et al., 2012). Some relations, like opposites (e.g., UP:DOWN) and exemplar-category "superordinate" relations (e.g., HAMMER:TOOL) yield better performance in comparison to other types of relations (e.g., category co-members: WRENCH:HAMMER; Jones, 2011; Sternberg & Nigro, 1980). In Kmiecik et al. (2019), participants demonstrated better performance verifying analogies composed of categorical relations ("kind of"; HAMMER:TOOL::SILVER :METAL) compared with compositional relations ("made of"; TIRE:RUBBER::CHAIN:LINK).[2] One reason for the better performance on categorical relations is that they are spontaneously activated during analogy as claimed by the micro-category account of analogy (Green et al., 2008) and are more accessible than other types of semantic relations (Schumacher et al., 2009). The automatic activation of the categorical relation may facilitate the mapping process in the far categorical analogies (WRENCH: TOOL::SAD:MOOD) by increasing the structural similarity between corresponding terms (i.e., both A and C as exemplars; both B and D as categories). Moreover, the constraint of the B-terms and D-terms as category labels may even pre-activate the correct D-term (e.g., MOOD) prior to presentation of the response options. Indeed, based on the complementary role activation model (Mather et al., 2014), the greater the degree of semantic constraint provided by the relational roles (A-term as category exemplar; B as the category), the faster the judgment. In contrast, causal and compositional relations provide less constraint on the possible B-terms and D-terms. For instance, LEATHER could be a material used in many different objects (gloves, jacket, etc.). Likewise, in the causal analogy, ALLERGY:SNEEZE::ENTERTAINMENT:LAUGHTER, the cause ENTERTAINMENT could produce other possible effects (joy, fun, relaxation, etc.). Therefore, we predict that performance will be better for these categorical analogies than for the causal or compositional analogies. Based on the micro-category account as well as the facilitative role of semantic constraint in the mapping and response selection processes, we further predict that far

[1] This differs somewhat from others' investigation of the analogy's association strength (e.g., Thibaut & French, 2016), which varies the association strength between both the A:B pairs and C:D pairs. We hold the A:B pairs constant across the high and low distracter salience conditions to focus on just the distracter salience between the C-terms with the possible D-terms.

[2] The compositional analogies in the Kmiecik et al. (2019) dataset are of the form "A is made of B" rather than the "B is made of A" used herein.

semantic distance and high distracter salience will impact performance less within the categorical than within the causal and compositional analogies.

Method

Participants

A total of 241 Wayne State University undergraduates (131 females; M_{age} = 21.96; SD_{age} = 6.08) completed the verbal analogy selection task for credit towards their psychology course as part of a larger study investigating individual differences in relational reasoning. We did not perform a power analysis to determine an a priori sample size; however, given our sample size (N = 241) and observed medium effect size for the three-way interaction (Cohen's f = .29), we were well powered (>.99) to observe this effect at our .05 α level.

Materials

Analogical pairs and analogies were sampled from prior studies on conceptual combination (Estes, 2003; Estes & Jones, 2006; Fenker et al., 2005; Jones et al., 2008) and analogy (Jones, 2011; Jones & Estes, 2015; Kmiecik et al., 2019). We then created a set of 60 analogies using these items consisting of 30 analogies that were semantically near and 30 that were semantically far based on Latent Semantic Analysis (LSA; Landauer et al., 1998; http://lsa.colorado.edu) based semantic distance as described below (see Table 1). The entire set of 60 analogies are shown with all the following measures in the Supplemental Materials—Spreadsheet of Analogies (https://osf.io/cd7b9).

Semantic distance As done in prior analogy studies (e.g., Green et al., 2010, 2012; Green et al., 2015; Jones & Estes, 2015; Kmiecik et al., 2019), we measured semantic distance using LSA, which is based on textual co-occurrence, to quantify semantic distance between the source and target word pairs. Semantic distance was calculated by subtracting the LSA cosine from 1 to produce a semantic distance score (Green et al., 2015), with higher scores indicating far semantic distances. Within each relation, pairs were grouped such that for the near analogies the A:B and C:D pairs had items from the same or similar domains and LSA semantic distance scores of .70 or below (e.g., bakery foods; OATMEAL:COOKIE::BANANA:MUFFIN), with the exception of one item, FEATHER:PILLOW::FOAM:CUSHION, that had a semantic distance of .80. The far analogies were formed with pairs from different domains, SPEEDING:TICKET::RUN:EXHAUSTED, and had LSA semantic distance scores of .90 or above with the exception of one causal analogy, SPEEDING:TICKET::RUN:EXHAUSTED, that had a semantic distance score of .71, most likely due to the co-occurrence of speeding and run. Thus, the near and far analogies were nonoverlapping on semantic distance except for those items. An independent-samples t test confirmed that the LSA-based semantic distance scores were greater for the semantically far A:B–C:D pairs (M = .96, SD = .06) than for the semantically near A:B–C:D pairs (M = .52, SD = .15), $t(58)$ = 15.46, p < .001, Cohen's d = 3.85.

However, the use of only LSA cosines to estimate semantic similarity is problematic (Beaty & Johnson, 2021). Since data collection, several new methods of assessing semantic distance have been developed, particular within the creativity and semantic priming literatures (Kennett, 2019; Kumar et al., 2020). One alternative is to assess semantic distance by combining multiple models of semantic distance into one latent variable. Thus, we also assessed semantic distance in our analogies using SemDis (Beaty & Johnson, 2021; http://semdis.wlu.psu.edu), which is based on five semantic space models. Because we were assessing the semantic distance between the A:B and C:D word pairs, we chose to use the recommended multiplicative model that takes the product of all word vectors to create a single vector for a phrase. The mean SemDis scores were again greater, indicating greater distance, for the far analogies (M = .92, SD = .04) than for the near ones (M = .75, SD = .11), $t(58)$ = 7.84, p < .001, Cohen's d = 2.05, although there was a small degree of overlap in the SemDis scores across conditions (see Supplemental Materials—Boxplots).

Distracter salience Each analogy (e.g., ACCOUNTANT:PROFESSION::CARROT:_____) was presented with either a high salient distracter (POTATO) or with a low salience distracter (RABBIT). The distracters (D′) were selected originally to have a semantic distance (1 − LSA cosine) that was greater than the correct answer D-term for the high salience D′ and less than that for the correct answer for the low salience D′. We also assessed semantic distance using the SemDis scores as described above between the C-term and each possible D-term response. There was only minimal overlap across the three conditions on both semantic distance measures (see Supplemental Materials—Boxplots).

Finally, given the limitations of using corpus-based semantic distance methods to predict human behavior (De Deyne et al., 2019; Kennett, 2019; Kennett et al., 2017; Kumar et al., 2020), we included a measure based on human ratings. As was done in prior studies examining distracter salience (e.g., Morrison et al., 2004; Thibaut et al., 2010), we assessed the association strength between the C-term with the correct answer (D-term) as well as with the distractors (D′-terms). Association strengths were assessed using the Small World of Words English Association Norms

Table 2 Distances between C-term with each D-term

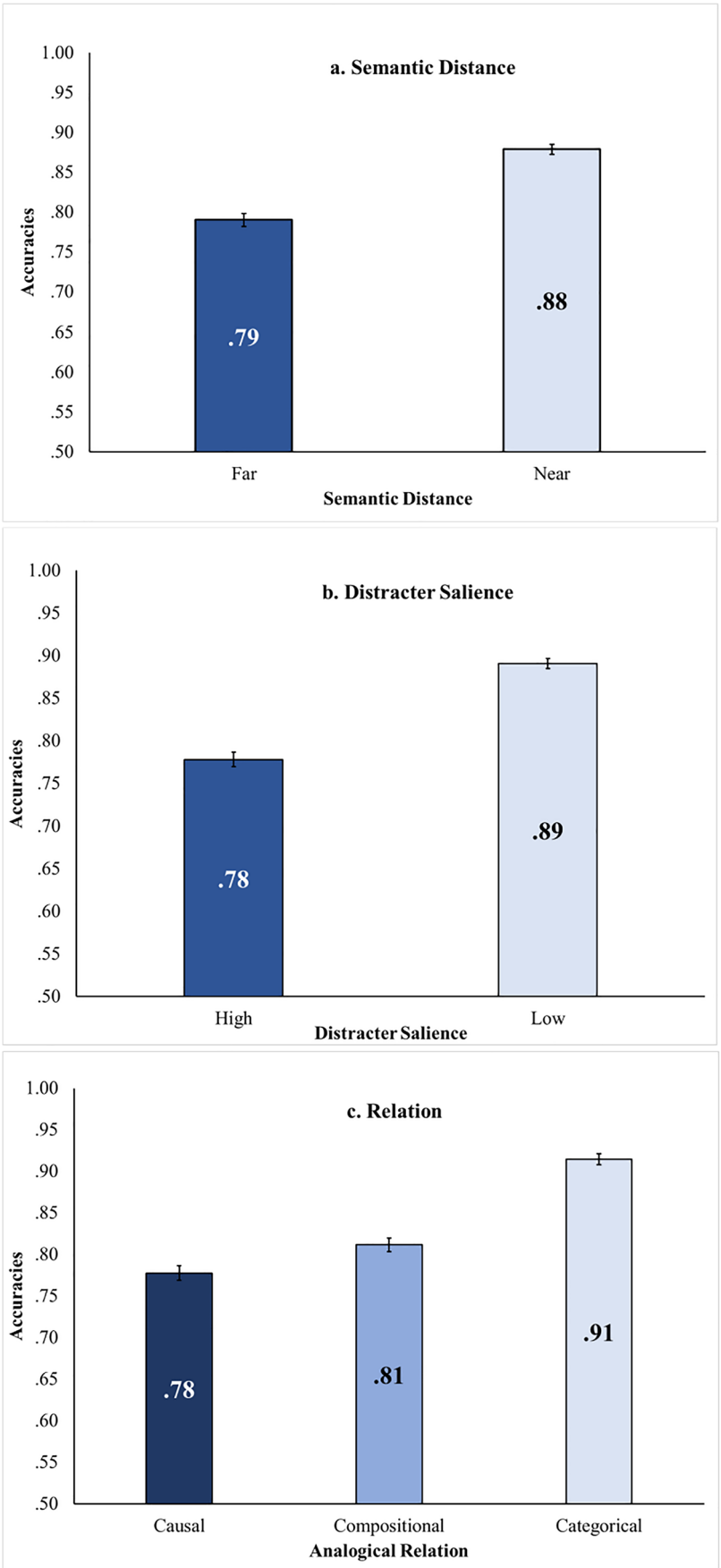
Measure	Correct D		High salient D'		Low salient D'		Repeated measures ANOVA	Pairwise comparisons with Bonferroni adjustments
	M	*SD*	*M*	*SD*	*M*	*SD*		
LSA-based Semantic Distance	.723	.161	.425	.185	.878	.057	$F(2, 118) = 101.19, p < .001, \eta_p^2 = .63$	Low Salient D' > Correct D > High Salient D', *ps* < .001
SemDis Semantic Distance	.715	.112	.555	.125	.825	.076	$F(2, 118) = 76.50, p < .001, \eta_p^2 = .56$	Low Salient D' > Correct D > High Salient D', *ps* < .001
SWOW-EN Association	.029	.046	.048	.057	.009	.018	$F(2, 118) = 9.37, p < .001, \eta_p^2 = .14$	High Salient D' > Correct D > Low Salient D', *ps* ≤ .002

Notes. Means and standard deviations of distance between the C-term with each of the D-terms. For the semantic distance measures, higher numbers indicate greater distances between the C and D terms. For the associations, smaller numbers indicate a greater closeness. Initial analyses included Semantic Distance (far, near) as a between-subjects factor. Neither the main effect (*ps* > .64) nor the interaction (*ps* > .20) were significant across the three measures, thereby showing a consistent pattern within both semantic distance conditions

(SWOW-EN), which indicate the number of times the D or D′ term was in the top three responses as an associate of the C-term (De Deyne et al., 2019). As shown in Table 2, repeated-measures ANOVAs for these three measures with planned contrasts across the three C:D pairs (C-term each with correct response, high-salient distracter, and low-salient distracter), verified that the correct answer was indeed semantically closer to the C-term in comparison to the low-salient distracter, but semantically farther than the high-salient distracter.

Prior studies (Bugaiska & Thibaut, 2015; Thibaut et al., 2010) also varied the association strengths between the A and B terms in addition to the C and D terms, with weakly associated analogies having low association strengths in both the A and B and the C and D terms. In our study, the A:B pairs and the C-term were the same across the distracter salience conditions. We assessed the semantic distance and association strengths for the A:B pairs and found that they did not differ between the near and far semantic distance conditions on the LSA-based scores, $t(58) = .70$, $p = .48$, SemDis scores, $t(58) = 1.18$, $p = .24$, and the SWOW-EN association strengths, $t(58) = .24$, $p = .81$.

Word familiarity As noted in Ichien et al. (2020), the familiarity of the words in the analogy can impact performance on verbal analogy tasks, with better performance on analogies with highly familiar words (HAPPY:SAD::FAT:SKINNY) than those with less familiar words (JUBILANT:MELANCHOLY::CORPULENT:GAUNT). To verify that our analogies and answer choices consisted of highly familiar words, we used the English Lexicon Project (Balota et al., 2007) to assess each word's familiarity using the age of acquisition (AoA; the age at which a word was learned; Kuperman et al., 2012) and frequency per million words (measured using the SUBTL frequency norms from the $SUBTLEX_{US}$ corpus that assess the more everyday use of the words in movie and television show subtitles; Brysbaert & New, 2009). AoA, SUBTL raw frequencies, and SUBTL log frequencies for each term as well as the *M*s and *SD*s for each D-term are included in the Word Familiarity tab of the Supplemental Materials spreadsheet. Both measures indicated a high level of word familiarity for all the terms in the item set (including the distracter terms) with an overall early AoA ($M = 6.41$, $SD = 2.19$) and a high frequency ($M = 30.03$, $SD = 55.43$). Given that all of the terms in the data set were words that were learned prior to age 13.5 (range: 2.50 [SPOON]–13.48 [LATEX]), it is unlikely that word familiarity would impact performance. Analyses further showed an overall lack of variation in the word familiarity measures across the semantic distance, distracter salience, and relation conditions. Given the extreme positive skew of the raw word frequencies (skew = 2.94), word frequencies are commonly analyzed using the log-transformed measures that were also available from the English Lexicon Project (Balota et al., 2007). For comparison between the semantic distance conditions and across the analogical relations, an aggregate measure was calculated by averaging the AoA and log frequencies across the analogical stem (A-, B-, and C-terms). For the distracter salience conditions, the AoA and log frequencies were compared across the correct D-terms, high salience distracter, and low salience distracter. As indicated by independent-samples *t* tests, the aggregated word familiarity for the analogical stem terms did not differ in AoA between the near ($M = 6.52$, $SD = 1.24$) and far ($M = 6.54$, $SD = 1.75$) items, $t(58) = -.057$, $p = .96$. Likewise, log frequencies did not differ between the near ($M = 2.86$, $SD = .38$) and far ($M = 2.77$, $SD = .37$) items, $t(58) = .94$, $p = .35$. Repeated-measures ANOVAs showed no differences across the correct, high-salience, or low salience D-terms for either the AoA, $F(2, 112) = .11$, $p = .89$, or for the log frequencies. $F(2, 112) = .22$, $p = .80$. Results of a one-way ANOVA showed no differences across the three relations on log frequencies, $F(2, 57) = .44$, $p = .65$. However, AoA varied across the analogical relations, $F(2, 57) = 5.83$, $p < .001$, $\eta_p^2 = .17$. Tukey post hoc tests showed AoA was higher


a. Semantic Distance
Accuracies
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
.79
.88
Far
Near
Semantic Distance
b. Distracter Salience
Accuracies
.78
.89
High
Low
Distracter Salience
c. Relation
Accuracies
.78
.81
.91
Causal
Compositional
Categorical
Analogical Relation

◂**Fig. 1** Main effects. Accuracies were higher with (**a**) greater semantic distance between the source (A:B) and target (C:D) pairs, (**b**) lower distractor salience between the C term and incorrect (D′) term, and (**c**) the categorical relations in comparison to the causal and compositional ones. Error bars represent ±1 *SEM*

for the causal analogies ($M = 7.36$, $SD = 1.22$) than for the compositional analogies ($M = 5.88$, $SD = 1.29$), $p < .001$, and the categorical ($M = 6.34$, $SD = 1.64$), $p = .063$ (albeit approaching significance), and with no difference between the latter two ($p = .56$). In sum, given the highly familiar A-, B-, and C-terms in the analogical stems and possible D-terms, as well as the consistency across semantic distance, distracter salience, and relation conditions, word familiarity was unlikely to impact performance on the verbal analogy task.

Procedure

The analogy selection task was run on computers using DirectRT software. Items were counterbalanced across experimental lists with each experimental list consisting of 60 analogies, 15 from each of the four semantic Distance × Distracter Salience conditions. Participants were told that they should answer each item as quickly as possible without sacrificing accuracy using the "1" and "2" keys on the number pad on the keyboard. Each trial began with the analogy stem (ACCOUNTANT:PROFESSION::CARROT: _____) presented in ALL CAPS and in red font horizontally centered above the middle of a black screen for 500 ms. Next, the numbered answer choices were presented in white font just below the center of the screen, "(1) = POTATO (2) = VEGETABLE" for 250 ms. The numerical order of the correct answer and distracter was counterbalanced across the experimental lists. Finally, participants were prompted to "Enter the number of your answer." Presentation order of the 60 experimental items was randomized across participants. Participants completed 12 practice trials prior to the 60 experimental trials. On practice trials the correct answer was displayed immediately after response selection.

Results

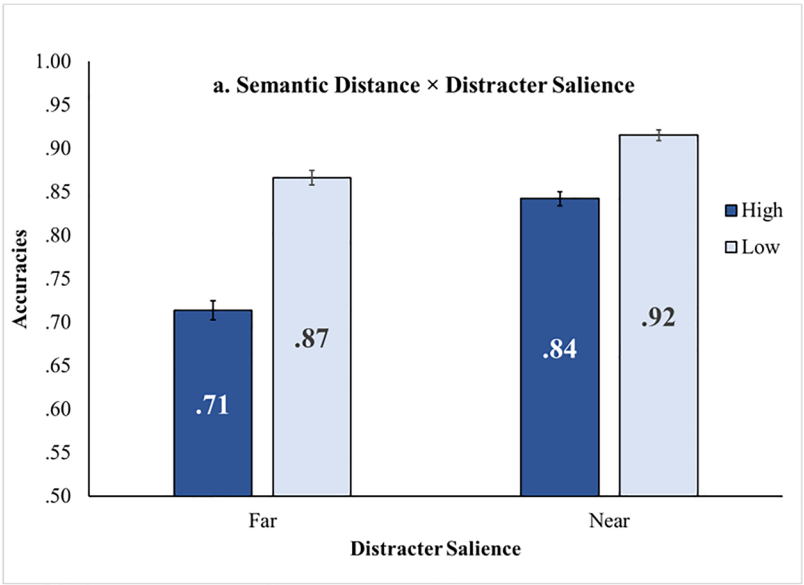
Participants' accuracies (proportion correct) across the 60 analogies were analyzed using a 2 (Semantic Distance: far, near) × 2 (Distracter Salience: high, low) × 3 (Relation: categorical, causal, compositional) repeated-measures ANOVA. All three main effects of Semantic Distance, Distracter Salience, and Relation were reliable (see Fig. 1). As predicted, accuracies were higher for the semantically near analogies than for the semantically far analogies, $F(1, 240) = 244.42$, $p < .001$, $\eta_p^2 = .50$. Likewise, analogies with low salience distracters had higher accuracies than those with high salience distracters, $F(1, 240) = 309.27$, $p < .001$, $\eta_p^2 = .56$. Performance also varied across the three relations, $F(2, 480) = 186.26$, $p < .001$, $\eta_p^2 = .44$. Pairwise comparisons (with Bonferroni adjustments) indicated that the categorical analogies had much higher accuracies than the compositional analogies, and the causal analogies (both *p*s < .001). Accuracies for the compositional analogies were higher than the causal, $p < .001$.

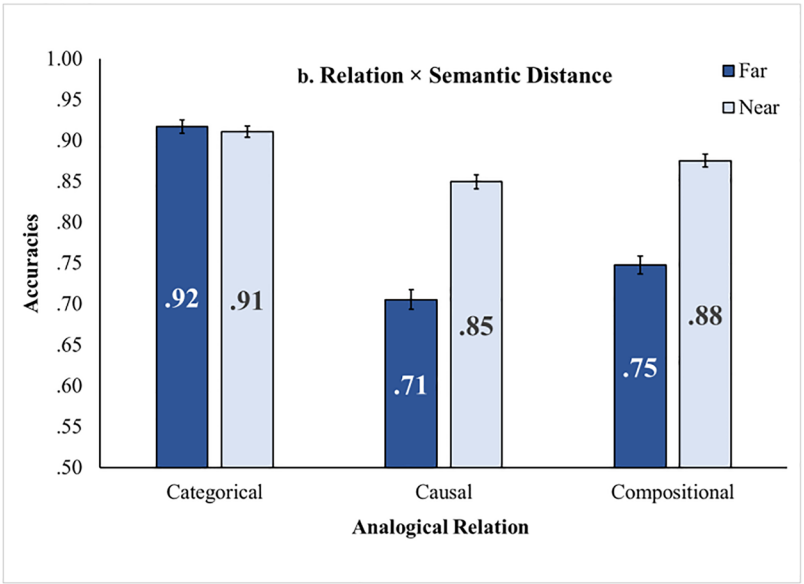
All three two-way interactions were also reliable (see Fig. 2). As predicted, the Semantic Distance × Distracter Salience interaction, $F(2, 240) = 34.14$, $p < .001$, $\eta_p^2 = .12$, showed a greater difference between the high and low distracter salience conditions within the far than within the near semantic distance analogies (.154 vs. .073). Recall that given the greater accessibility of the categorical in comparison to the causal and compositional relations, both far semantic distance and high distracter salience were predicted to have less of a detrimental impact within the categorical analogies. As predicted, the Relation × Semantic Distance interaction, $F(2, 480) = 76.46$, $p < .001$, $\eta_p^2 = .24$, showed almost no difference between the semantic distance conditions (near minus far) within the categorical analogies, but greater differences within the causal and compositional analogies. Similarly, the Relation × Distracter Salience interaction, $F(2, 480) = 26.06$, $p < .001$, $\eta_p^2 = .10$, indicated a smaller difference (low minus high) within the categorical analogies than within the causal or compositional ones.

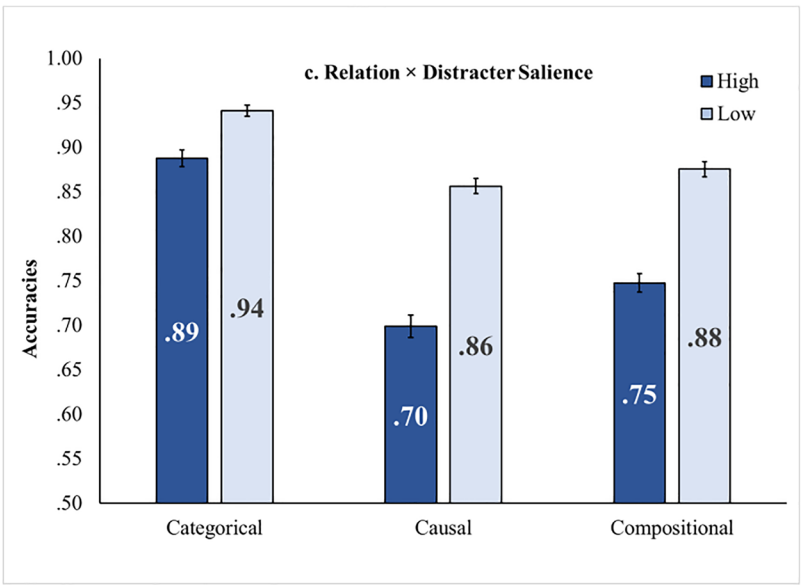
Finally, we observed a reliable three-way interaction, $F(2, 480) = 20.22$, $p < .001$, $\eta_p^2 = .08$ (see Fig. 3). Additional ANOVAs examined the effects of semantic distance and distracter salience within each relation. Within the causal analogies, semantic distance $F(1, 240) = 177.49$, $p < .001$, $\eta_p^2 = .43$, distracter salience, $F(1, 240) = 159.99$, $p < .001$, $\eta_p^2 = .40$, and their interaction, $F(1, 240) = 14.90$, $p < .001$, $\eta_p^2 = .06$, affected accuracies. The same pattern occurred within the compositional analogies, with semantic distance, $F(1, 240) = 159.48$, $p < .001$, $\eta_p^2 = .40$, distracter salience, $F(1, 240) = 145.70$, $p < .001$, $\eta_p^2 = .38$, and their interaction, $F(1, 240) = 55.54$, $p < .001$, $\eta_p^2 = .18$, affecting accuracies. However, within the categorical analogies, only distracter salience impacted performance ($M_{high} = .89$, $M_{low} = .94$), $F(1, 240) = 37.16$, $p < .001$, $\eta_p^2 = .13$ with no difference between the near and far semantic distance conditions, $F(1, 240) < 1$, $p = .40$, and no interaction, $F(1, 240) = 1.43$, $p = .23$.

Discussion

Our study was the first to investigate the interactive effects of semantic distance, distracter salience, and analogical relation type (categorical, compositional, and causal) on


a. Semantic Distance × Distracter Salience
Accuracies
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
.71
.87
.84
.92
High
Low
Far
Near
Distracter Salience


b. Relation × Semantic Distance
Accuracies
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
.92
.91
.71
.85
.75
.88
Far
Near
Categorical
Causal
Compositional
Analogical Relation


c. Relation × Distracter Salience
Accuracies
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
.89
.94
.70
.86
.75
.88
High
Low
Categorical
Causal
Compositional

◂**Fig. 2** Two-way interactions. (**a**) High distracter salience lowered accuracies more within the far than near analogies. (**b**) Far semantic distances lowered accuracies within the causal and compositional analogies but not within the categorical ones. (**c**) High distractor salience lowered accuracies for all relations, but to a greater extent for the causal and compositional ones. Error bars represent ±1 *SEM*

verbal analogy performance. Consistent with prior studies, we observed higher accuracies for semantically near than far analogies (e.g., Jones & Estes, 2015), and for analogies with low than high salience distracters (e.g., Morrison et al., 2004). Performance was higher for the categorical relations than for the compositional and causal relations. Most notably, our results are the first to demonstrate joint facilitative effects of near semantic distance and low distracter salience, while also showing that the strength of their influence varies across different relations. In turn, these main effects and interactions extend prior research and have important implications as discussed below.

Implications

The semantic distance effect supports the hypothesis that semantic similarity between domains facilitates the one-to-one mapping of corresponding analogy terms (Gentner & Smith, 2012; Holyoak & Thagard, 1997). That is, mapping between the far analogies relies on a more abstracted structural similarity between relational roles. Thus, the greater structural *and* semantic similarity between the source and target resulted in more efficient mapping and thus better performance. However, when a high salience distracter was presented along with the correct D-term, the mapping process was derailed during response selection, as shown by the robust distracter salience effect.

Prior results of distracter salience were limited to children (e.g., Thibaut et al., 2010, except for Bugaiska & Thibaut, 2015) and patients with frontal lobe damage (Krawczyk et al., 2008; Morrison et al., 2004). Moreover, these prior studies used different analogy stems across distracter conditions (Bugaiska & Thibaut, 2015) or included a perceptual distracter (Krawczyk et al., 2008), thereby potentially confounding distracter salience with other aspects of the analogy. Our results extend the findings of distracter salience to younger adults using a highly controlled stimulus set that specifically manipulated the semantic association strengths between the C-term and distracters. Notably, the obtained interaction between semantic distance and distracter salience demonstrated that a high salience distracter can derail the mapping process more for far than for near analogies. Prior studies that showed strong effects of lure items usually presented three or four semantic distracters (Jones, 2011; Jones & Estes, 2015; Thibaut et al., 2010); however, our observed distracter salience effects occurred with only one distracter, thus further showing the extent to which semantic information influences effective analogical mapping.

The greater accuracy for the categorical analogies supports the proposition that categorical relations are automatically activated as proposed by the micro-category account of analogy (Green et al., 2008), and that exemplar-category word pairs generate greater semantic constraint for the possible second term. In fact, the constraint of the exemplar-category relation was so strong that accuracies were equally high between the far and near semantic distances within this relation, though high distracter salience still impaired performance. Moreover, we speculate that the reduced performance on the compositional and causal analogies was due to the relative lack of semantic constraint in the process of analogical inference. In addition to replicating prior findings of superior performance for these categorical relations (e.g., Kmiecik et al., 2019), our results demonstrated the important role of analogical relations in mapping. Performance on categorical analogies was unaffected by the semantic distance between source-target word pairs, whereas accuracies were higher on causal and compositional analogies when semantic distance was near. However, the lure of the more salient distracter still impacted performance even for the categorical relations, suggesting that inhibitory control plays an important role in analogy (e.g., Doumas et al., 2018; Morrison et al., 2004; Morrison et al., 2011; Richland et al., 2006).

Limitations and future directions

Our study was not designed to discern the exact underlying reason for the superior performance on categorical relations (automatic activation of the categorical relation and/or the greater constraint of this relation). Future studies would need to compare this relation with other equally constraining analogical relations, such as *opposite,* that similarly constrains to one possible second term within each pair. Given the similarly better performance for the categorical and opposite relations found in prior studies (Sternberg & Nigro, 1980), semantic constraint may be an equally viable explanation as the micro-category account's proposed automatic activation for the categorical analogies' higher accuracies.

The extent to which a given word pair represents its assigned relation and how well the same relation is represented in both the source and target pairs could also affect analogical mapping (Popov et al., 2017). For example, the categorical analogies may be good examples of the exemplar–category relation, whereas the compositional analogies represent a broader relational category that includes more specific relational pairs representing subtypes of *fabric of clothing* (e.g., SATIN:DRESS), *metal of objects* (e.g., GOLD:EARRING), and *ingredients of food* (e.g., OATMEAL:COOKIE). Despite their careful construction, our reliance on only computational measures to assess semantic

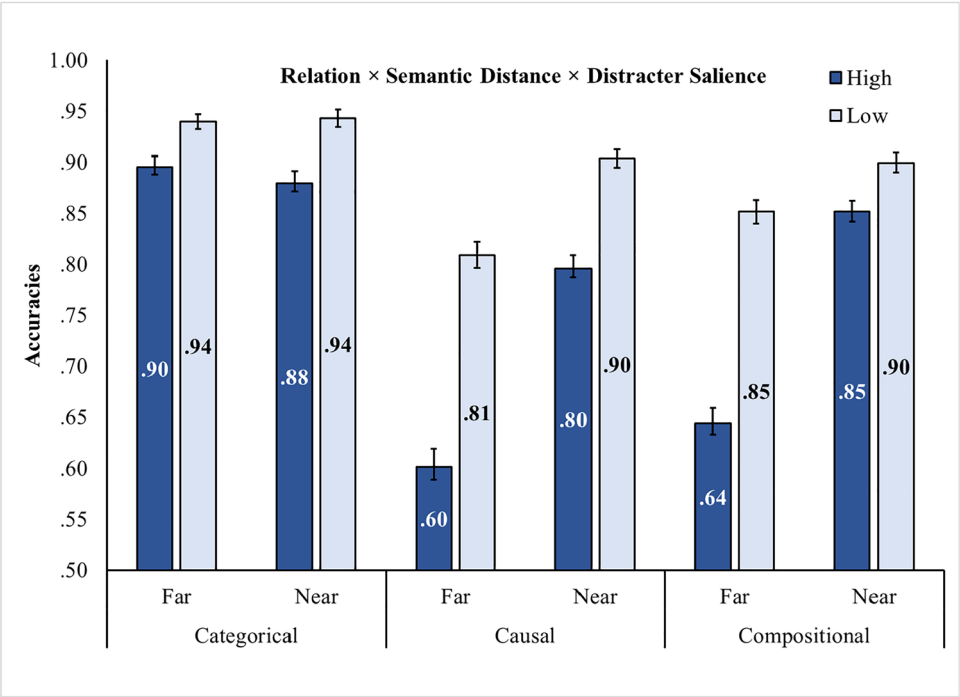


Fig. 3 Three-way interaction. Within the causal and compositional relations, the combination of high distracter salience and far semantic distance had a large detrimental effect on accuracies in comparison to the other three Semantic Distance × Distracter Salience conditions. However, within the categorical relation, only high distracter salience lowered accuracies and only to a small extent for both semantic distance conditions. Error bars represent ±1 *SEM*

distance may not have corresponded well with human judgment (e.g., Kumar et al., 2020). Indeed, the far semantic distance was conflated with the inclusion of different relational sub-types between the pairs (e.g., FLOUR:TORTILLA::SILK:TIE). If the level of relational inference were at this specific relational subtype rather than at the broader compositional relation, then it would be more challenging to detect the relational roles.

The current study presented 60 analogies that were evenly divided across three relations with each relation representing 33% of the items on a given experimental list. Given our robust relation effect, one future direction could be to assess whether presenting a higher proportion of the more challenging analogical relations would improve performance on them. The relational luring hypothesis postulates that activation strengths of relations increase with each presented exemplar (Popov et al., 2017); thereby, we speculate that performance would increase for causal and other more challenging relations when presented at higher proportions.

Conclusion

We extended prior work showing the importance of semantic distance and distracter salience on analogical mapping by showing that the strength of these effects differs across relations. High distracter salience, but not semantic distance, impaired performance on categorical analogies. In contrast, both high distracter salience and far semantic distance impaired performance on compositional and causal analogies.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13423-022-02062-8.

Acknowledgments We thank Megan Phillips for her assistance in obtaining the SWOW-English association norms.

References

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods, 39*, 445–459.

Beaty, R. E., & Johnson, D. R. (2021). Automating creativity assessment with SemDis: An open platform for computing semantic distance. *Behaviour Research Methods, 53,* 757–780.

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*(4), 977–990.

Bugaiska, A., & Thibaut, J.-P. (2015). Analogical reasoning and aging: The processing speed and inhibition hypothesis. *Aging, Neuropsychology, and Cognition, 22*, 340–356.

Bunge, S. A., Carter W., Badre, D., & Wagner, A. D. (2005) Analogical reasoning and prefrontal cortex: Evidence for separable retrieval and integration mechanisms. *Cerebral Cortex, 15*, 239–249.

De Deyne, S., Navarro, D. J., Perfors, A., Brysbaert, M., & Storms, G. (2019). The "Small World of Words" English word association norms for over 12,000 cue words. *Behavior Research Methods, 51*, 987–1006.

Doumas, L. A. A., Morrison, R. G., & Richland, L. E. (2018). Individual differences in relational learning and analogical reasoning: A computational model of longitudinal change. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2018.01235

Estes, Z. (2003). Attributive and relational processes in nominal combination. *Journal of Memory and Language, 48*, 304–319.

Estes, Z., & Jones, L. L. (2006). Priming via relational similarity: A copper horse is faster when seen through a glass eye. *Journal of Memory and Language, 55*, 89–101.

Fenker, D. B., Waldmann, M. R., & Holyoak, K. J. (2005). Accessing causal relations in semantic memory. *Memory & Cognition, 33*, 1036–1046.

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

Gentner, D. & Kurtz, K. J. (2006). Relations, objects, and the composition of analogies. *Cognitive Science, 30*, 609–642.

Gentner, D., & Forbus, K. D. (2011). Computational models of analogy. *WIREs Cognitive Science, 2*(3), 266–276. https://doi.org/10.1002/wcs.105

Gentner, D., & Smith, L. (2012). Analogical reasoning. In: V. S. Ramachandran (Ed.), *Encyclopedia of human behavior* (2nd ed., pp. 130–136). Elsevier.

Gentner, D., & Maravilla, F. (2018). Analogical reasoning. In Ball, L. J., & Thompson, V. A. (eds.), *International Handbook of Thinking & Reasoning* (pp.186–203). Psychology Press.

Glady, Y., French, R., & Thibaut, J.-P. (2016). Comparing competing views of analogy making using eye-tracking technology. In A. Papafragou, D. Grodner, D. Mirman, & J. C. Trueswell (Eds.), *Proceedings of the 38th Annual Conference of the Cognitive Science Society* (p. 1349). Cognitive Science Society.

Gordon, P. C., & Moser, S. (2007). Insight into analogies: Evidence from eye movements, *Visual Cognition, 15*(1), 20–35, https://doi.org/10.1080/13506280600871891

Green, A. E. (2016). Creativity, within reason: Semantic distance and dynamic state creativity in relational thinking and reasoning. *Current Directions in Psychological Science, 25*, 28–35.

Green, A. E., Fugelsang, J. A., & Dunbar, K. N. (2006). Automatic activation of categorical and abstract relations in analogical reasoning. *Memory & Cognition, 34*(7), 1414–1421.

Green, A. E., Fugelsang, J. A., Kraemer, D. J. M., & Dunbar, K. N. (2008). The micro-category account of analogy. *Cognition, 106*, 1004–1016.

Green, A. E., Kraemer, D. J. M., Fugelsang, J. A., Gray, J. R., & Dunbar, K. N. (2010). Connecting long distance: Semantic distance in analogical reasoning modulates frontopolar cortex activity. *Cerebral Cortex, 10,* 70–76.

Green, A. E., Kraemer, D. J. M., Fugelsang, J. A., Gray, J. R., & Dunbar, K. N. (2012). Neural correlates of creativity in analogical reasoning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*(2), 264–272.

Green, A. E., Kenworthy, L., Mosner, M. G., Gallagher, N. M., Fearon, E. W., Balhana, C. D., & Yerys, B. E. (2014). Abstract analogical reasoning in high-functioning children with autism spectrum disorders. *Autism Research*, *7*, 677–686.

Green, A. E., Cohen, M. S., Raab, H. A., Yedibalian, C. G., & Gray, J. R. (2015). Frontopolar activity and connectivity support dynamic conscious augmentation of creative state. *Human Brain Mapping, 36*(3), 923–934. https://doi.org/10.1002/hbm.22676

Holyoak, K. J. (2012). Analogy and relational reasoning. In K. J. Holyoak & R. G. Morrison (Eds.), *The Oxford handbook of thinking and reasoning* (pp. 234–259). Oxford University Press.

Holyoak, K. J., & Thagard, P. (1997). The analogical mind. *American Psychologist, 52*(1), 35–44. https://doi.org/10.1037/0003-066X.52.1.35

Hoyos, C., & Gentner, D. (2017). Generating explanations via analogical comparison. *Psychonomic Bulletin & Review, 24*, 1364–1374.

Ichien, N., Lu, H., & Holyoak, K. J. (2020). Verbal analogy problem sets: An inventory of testing materials. *Behavior Research Methods*. https://doi.org/10.3758/s13428-019-01312-3

Jones, L. L. (2011). Relational constraint and format in verbal analogy. *European Perspective on Cognitive Science*. New Bulgarian University Press. https://scholar.google.com/citations?view_op=view_citation&hl=en&user=Z78VJYAAAAAJ&cstart=20&pagesize=80&citation_for_view=Z78VJYAAAAAJ:YsMSGLbcyi4C

Jones, L. L., & Estes, Z. (2015). Convergent and divergent thinking in verbal analogy. *Thinking & Reasoning, 21*, 473-500.

Jones, L. L., Marsh, R. L., & Estes, Z. (2008). An asymmetric effect of relational integration on recognition memory. *The Quarterly Journal of Experimental Psychology, 61*, 1169-1176.

Jurgens, D. A., Mohammad, S. M., Turney, P. D., & Holyoak, K. J. (2012). SemEval-2012 Task 2: Measuring degrees of relational similarity. *Proceedings of the First Joint Conference on Lexical and Computational Semantics (*SEM)* (pp. 356–364). Association for Computational Linguistics.

Kennett, Y. N. (2019). What can quantitative measures tell us about creativity? *Current Opinion in Behavioral Sciences, 27*, 11–16.

Kennett, Y. N., Levi, E., Anaki, D., & Faust, M. (2017). The semantic distance task: Quantifying semantic distance with semantic network path length. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43*, 1470–1489.

Kmiecik, M. J., Brisson, R. J., & Morrison, R. G. (2019). The time course of semantic relational processing during verbal analogical reasoning. *Brain & Cognition, 129*, 25–34.

Krawczyk, D. C., Morrison, R. G., Viskontas, I., Holyoak, K. J., Chow, T. W., Mendez, M. F., Miller, B. L., & Knowlton, B. J. (2008). Distraction during relational reasoning: The role of prefrontal cortex in interference control. *Neuropsychologia, 46*, 2020–2032.

Kumar, A.A., Balota, D.A., & Steyvers, M. (2020). Distant connectivity and multiple-step priming in large-scale semantic networks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 46*(12), 2261–2276.

Kuperman, V., Stadthagen-Gonzalez, H., & Brysbaert, M. (2012). Age-of-acquisition ratings for 30,000 English words. *Behavior Research Methods, 44*, 978–990.

Landauer, T. K., Foltz, P. W., & Laham, D. (1998). Introduction to latent semantic analysis. *Discourse Processes, 25*, 259–284.

Mather, E., Jones, L. L., & Estes, Z. (2014). Priming by relational integration in perceptual identification and Stroop colour naming. *Journal of Memory and Language, 71*, 57–70.

Morrison, R. G., Krawczyk, D. C., Holyoak, K. J., Hummel, J. E., Chow, T. W., Miller, B. L., & Knowlton, B. J. (2004). A neurocomputational model of analogical reasoning and its breakdown in frontotemporal lobar degeneration. *Journal of Cognitive Neuroscience, 16*, 260–271.

Morrison, R. G., Doumas, L. A. A., & Richland, L. E. (2011). A computational account of children's analogical reasoning: Balancing inhibitory control in working memory and relational representation. *Developmental Science, 14*(3), 516–529. https://doi.org/10.1111/j.1467-7687.2010.00999.x

Popov, V., Hristova, P., & Anders, R. (2017). The relational luring effect: Retrieval of relational information during associative recognition. *Journal of Experimental Psychology: General, 146*(5), 722–745.

Rattermann, M. J., & Gentner, D. (1998). More evidence for a relational shift in the development of analogy: Children's performance on a causal-mapping task. *Cognitive Development, 13*, 453–478.

Richland, L. E., Morrison, R. G., & Holyoak, K. J. (2006). Children's development of analogical reasoning: Insights from scene analogy problems. *Journal of Experimental Child Psychology, 94,* 249–273.

Schumacher, R., Wirth, M., Perrig, W. J., Strik, W., & Koenig, T. (2009). ERP correlates of superordinate category activation. *International Journal of Psychophysiology, 72*, 134–144.

Sternberg, R. J. (1977). Component processes in analogical reasoning. *Psychological Review, 84*, 353–378.

Sternberg, R. J., & Nigro, G. (1980). Developmental patterns in the solution of verbal analogies. *Child Development, 51*, 27–38.

Thibaut, J.-P. & French, R. (2016). Analogical reasoning, control, and executive functions: A developmental investigation with eye-tracking. *Cognitive Development, 38*, 10–26.

Thibaut, J.-P., French, R., & Vezneva, M. (2010). Cognitive load and semantic analogies: Searching semantic space. *Psychonomic Bulletin & Review, 17*, 569–574.

Thibaut, J.-P., French, R., Missault, A., Gérard, Y., & Glady, Y. (2011a). In the eyes of the beholder: What eye-tracking reveals about analogy-making strategies in children and adults. *Proceedings of the Annual Meeting of the Cognitive Science Society, 33*(33).

Thibaut, J.-P., French, R., Vezneva, M., Gérard, Y., & Glady, Y. (2011b). Semantic analogies by young children: Testing the role of inhibition. *European Perspective on Cognitive Science*. New Bulgarian University Press. https://www.researchgate.net/profile/Robert-French-11/publication/228508560_Semantic_Analogies_by_Young_Children_Testing_the_Role_of_Inhibition/links/0fcfd51128b13e7119000000/Semantic-Analogies-by-Young-Children-Testing-the-Role-of-Inhibition.pdf

Vendetti, M. S., Knowlton, B. J., & Holyoak, K. J. (2012). The impact of semantic distance and induced stress on analogical reasoning: A neurocomputational account. *Cognitive, Affective, & Behavioral Neuroscience, 12*, 804–812.

Vendetti, M. S., Wu, A., & Holyoak, K. J. (2014). Far-out thinking: Generating solutions to distant analogies promotes relational thinking. *Psychological Science, 25*, 928–933.

Vendetti, M. S., Starr, A., Johnson, E. L., Modavi, K., & Bunge, S. A. (2017). Eye movements reveal optimal strategies for analogical reasoning. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.00932

Weinberger, A. B., Iyer, H., & Green, A. E. (2016). Conscious augmentation of creative state enhances "real" creativity in open-ended analogical reasoning. *PLOS One, 11*(3), Article e0150773. https://doi.org/10.1371/journal.pone.0150773

Open practice statement The data (participants' mean accuracies by condition) as well as all Supplemental Material (Spreadsheet of Analogies and Boxplots) are available on the first author's ResearchGate page (https://www.researchgate.net/project/Verbal-Analogy). Then, go to Project Log tab to download the materials under the "Verbal Analogy" project. These materials are also available in the Open Science Framework for the project "Verbal Analogy–Semantic Distance, Distracter Salience, and Analogical Relation" (https://osf.io/cd7b9). The experiment was not preregistered.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.