Whether and How Semantic Similarity Impairs Short-Term Memory: A Test with a New Index of
Semantic Similarity

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Abstract

Semantic similarity appears to have a facilitative effect on short-term memory (STM), which contrasts with the detrimental effects of phonological and visual similarity on STM. Given that STM theories generally posit detrimental effects of similarity, it is theoretically and empirically important to test the semantic similarity effect. Recently, a review study proposed that semantic similarity per se would have a detrimental effect while semantic association and additional retrieval cues, which are facilitative of STM, would work as confounding factors for the semantic similarity effect. The present study tested this view by minimizing the influence of these possible confounding factors in the experiment and by utilizing a new index of semantic similarity in the analysis. The results of the present study indicated that the semantic similarity indeed had a detrimental effect on immediate serial recall correct-in-position scores. An examination based on two other scoring methods (i.e., item correct and absolute order errors) further suggested that the locus of the detrimental effect of semantic similarity is in order memory. In addition, other semantico-lexical variables (e.g., word length, frequency, and imageability) were also analyzed. Patterns of these variables' effects on item memory were complementary to the effect of semantic similarity on order memory. From a theoretical point of view, as the detrimental effect of semantic similarity demonstrated by the present study is comparable to phonological and visual similarity effects, this finding implies a store based on semantic information or a general process for various types of information.

Keywords: semantic similarity, short-term memory, serial recall, semantic association, web-based task

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1. Introduction

The similarity of stimulus properties, in general, impairs short-term memory (STM): STM research has demonstrated detrimental effects of phonological (Baddeley, Lewis, & Vallar, 1984; Conrad, 1964; Poirier & Saint-Aubin, 1996), tonal (Williamson, Baddeley, & Hitch, 2010), and visual similarity (Avons & Mason, 1999; Poirier, Saint-Aubin, Musselwhite, Mohanadas, & Mahammed, 2007; Saito, Logie, Morita, & Law, 2008). Ishiguro and Saito (2019) further suggested that the detrimental effect of face similarity on STM (Smyth, Hay, Hitch, & Horton, 2005) can be viewed as a detrimental effect of social trait similarity by implying that social dimensions of faces influence perceived face similarity (cf. Todorov, Said, Engell, & Oosterhof, 2008). Taken together, various types of psychological characteristics exhibit a similarity disadvantage for STM. Demonstrations of similarity effects—particularly the phonological similarity effect—have received theoretical attention, and as a result, a considerable number of STM theories and models postulate detrimental effects of similarity (Botvinick & Plaut, 2006; Brown, Neath, & Chater, 2007; Farrell, 2006; Henson, 1998; Nairne, 1990; Page & Norris, 1998; for a review, see Hurlstone, Hitch, & Baddeley, 2014). According to these STM theories and models, similarity leads to confusion or competition between items, which impairs STM performance. The similarity disadvantage is, therefore, empirically and theoretically underpinned in STM research.

Nevertheless, a *facilitative effect of semantic similarity* on STM has been frequently reported in studies using the immediate serial recall task (e.g., Guérard & Saint-Aubin, 2012; Neale & Tehan, 2007; Poirier & Saint-Aubin, 1995; Saint-Aubin, Ouellette, & Poirier, 2005;

Saint-Aubin & Poirier, 1999a; for a review, see Ishiguro & Saito, 2020). This suggests that the semantic similarity effect may be an exception among other similarity effects and that testing the semantic similarity effect is empirically necessary. Furthermore, it is theoretically important to investigate a similarity effect given that a similarity effect based on a certain type of information can be seen as evidence for a mnemonic process/mechanism based on that type of information. For instance, phonological and visual similarity effects are taken as corroborative evidence for phonological and visual stores in the working memory framework (e.g., the *phonological loop* and *visuo-spatial sketchpad*; Baddeley, 1986; Baddeley & Logie, 1999; see also Camos & Barrouillet, 2014).

This study tests whether the semantic similarity effect is detrimental or facilitative to STM by using the immediate serial recall task and a common scoring method for this task (i.e., *correct-in-position* scoring). Referring to Ishiguro and Saito (2020), we aimed to minimize effects by possible confounding factors in this study. This study further examines how semantic similarity impairs immediate serial recall by evaluating effects of semantic similarity on item and order memory with two additional scoring methods (i.e., *item correct* and *absolute order errors* scorings). Prior to explaining the current study in detail, we will begin by describing previous studies on semantic similarity, explanations for the semantic similarity effect, and a critical review of previous studies based on findings from a recent review study.

1.1. Observations and Explanations of Semantic Similarity

Previous STM studies on semantic similarity have typically compared memory performance for lists of semantically similar words with that for lists of semantically dissimilar words. In a typical list construction, semantically similar words (e.g., “*cat, deer, dog, horse, lion, tiger*” or “*climb, mountain, peak, steep, summit, valley*”) are those belonging to the same

taxonomical category (e.g., “*animal*”) or those related to a common theme (e.g., “*mountain*”) (for a classification of manipulations of semantic similarity, see Tse, 2009). Accordingly, a semantically similar word list contains categorically or associatively related words. Semantically dissimilar word lists are typically constructed by drawing words from different categories or themes: a semantically dissimilar word list includes categorically or associatively unrelated words. Studies have demonstrated that memory performance for similar word lists is higher than that for dissimilar word lists, using data of correct-in-position scores from the immediate serial recall task, suggesting a facilitative effect of semantic similarity. Note that correct-in-position scoring, which counts to-be-remembered items recalled at their correct positions, is commonly used for the immediate serial recall task and that the detrimental effect of phonological similarity is well-replicated by correct-in-position scoring data of the immediate serial recall task (e.g., Page, Madge, Cumming, & Norris, 2007; Poirier & Saint-Aubin, 1996; Watkins, Watkins, & Crowder, 1974), which sharply contrasts with a facilitative effect of semantic similarity.

As correct-in-position scoring is thought to reflect both item and order memory (Nairne & Kelley, 2004; Saint-Aubin & Poirier, 1999b), several studies have used other scoring methods to investigate semantic similarity effects on item and order memory separately. Item correct, or the free recall criterion, counts recalled to-be-remembered items regardless of position. As item correct scoring ignores the order of items but focuses on their identity, it is thought to measure item memory. Conditionalized order errors refer to the number of items recalled at the wrong position (i.e., absolute order errors), divided/corrected by the number of to-be-remembered items recalled regardless of position (i.e., item correct). Conditionalized order errors are thought to reflect order errors, controlling for item memory. By these two scoring methods, it has been suggested that semantic similarity is facilitative to item memory while it is detrimental or neutral

to order memory (Poirier & Saint-Aubin, 1995; Saint-Aubin et al., 2005; Saint-Aubin & Poirier, 1999a; Tse, 2009; Tse, Li, & Altarriba, 2011).

These findings of semantic similarity effects on STM can be explained by the extended redintegration theory (Saint-Aubin et al., 2005; Tse, 2009), which addresses semantic similarity effects by adapting the original redintegration theory (Hulme, Maughan, & Brown, 1991; Hulme et al., 1997) to the domain of semantic similarity. The original redintegration theory postulates that memory representations suffer from interference and/or temporal decay, and as a result, they are degraded by the time of retrieval. According to this theory, the redintegration process, which recovers memory representations by using preexisting knowledge, occurs at retrieval. The extended redintegration theory adopted the redintegration process from the original redintegration theory and further broadened the original theory to include semantic similarity effects in its theoretical scope by assuming two additional mechanisms: *spreading activation in associative networks* and *cuing by additional retrieval cues*. Positing pre-experimental associations between words in similar word lists (e.g., the association between “cat” and “dog” or that between “climb” and “peak”), Tse (2009) suggested that encoding/retrieval of a word activates representations of other words associated with that word (for a similar idea, see Kowialiewski & Majerus, 2020). Such spreading activation in associative networks is thought to facilitate the redintegration process. Additional retrieval cues are labels generated and utilized by participants (Poirier & Saint-Aubin, 1995; Saint-Aubin & Poirier, 1999a; Tse, 2009). Even when such labels are not provided explicitly by an experimenter, participants are assumed to generate a label for a similar word list (e.g., a label of “animal” for “cat, deer, dog, horse, lion, tiger” or “mountain” for “climb, mountain, peak, steep, summit, valley”) and utilize that label as an additional retrieval cue at the integration process. To sum up, the extended redintegration theory

(Saint-Aubin et al., 2005; Tse, 2009) states that semantic similarity enables the mechanisms of the spreading activation in associative networks and/or the cuing by additional retrieval cues, which facilitate the integration process. Given that the redintegration process refers to the recovery of degraded memory representations, the extended redintegration theory can explain the facilitative effect of semantic similarity on item memory as enhancement in the recovery of memory representations' identities. In addition, the redintegration theory attributes the increase in order errors caused by semantic similarity to a form of confusion known as the interpretation problem. For example, when recalling the first word (e.g., "cat") in a list (e.g., "cat, deer, dog, horse, lion, tiger"), the degraded representation of the first word can be matched with the third word (e.g., "dog") inappropriately, and as a result, that wrong word can be recovered.

Specifically, Saint-Aubin et al. (2005) proposed that features of semantically similar words overlap with each other and feature overlaps lead to the interpretation problem. We note that a variety of STM theories or models, as well as the extended redintegration theory, propose confusion as an underlying mechanism of the detrimental effect of similarity (e.g., Botvinick & Plaut, 2006; Brown et al., 2007; Henson, 1998).

1.2. A Critical Review of Explanations of Semantic Similarity

The extended redintegration theory (Saint-Aubin et al., 2005; Tse, 2009) can explain effects of semantic similarity on both item and order memory. It, however, requires that semantically similar words should be semantically associated with each other (i.e., semantic association as a prerequisite of the mechanism of the spreading activation in associative networks) and/or that labels should be generated for semantically similar word lists (i.e., label-word relationships as a prerequisite of the mechanism of the cuing by additional retrieval cues). Although these requirements seem reasonable given that previous studies manipulated semantic

similarity by contrasting associatively or categorically related word lists with unrelated word lists, Ishiguro and Saito (2020) pointed out that a semantic similarity between words is conceptually different from either a semantic association between words or a relationship between words and a generated label. They also conducted a meta-regression analysis of past studies' correct-in-position score data of the serial recall task with their proposed indices for semantic similarity and semantic association. The results of their meta-regression analysis suggested that manipulation strength for semantic similarity decreases the effect size of similarity advantage while that for semantic association increases it. A statistically significant intercept with a positive value was also implied. They interpreted these results as follows. First, manipulations used in previous studies have three effects via semantic similarity, semantic association, and label cuing, which are alluded to by the extended redintegration theory. Second, semantic similarity per se has a detrimental effect on serial recall. Third, semantic association, as a confounding factor, contributes to the apparent semantic similarity advantage. Last, the positive intercept, which was statistically separated from the effects of semantic similarity or semantic association in their meta-analytic study, can be viewed as showing label cuing's facilitative effect. In addition, they reviewed data from the serial recall task scored by item correct and conditionalized order error scoring and data from the serial reconstruction of order task (as a task of order memory). In reviewing the patterns of influence of semantic similarity and semantic association on memory performance assessed by different tasks and by different scoring methods, Ishiguro and Saito offered a view that semantic similarity is detrimental to order memory but neutral to item memory whereas semantic association is neutral to order memory but facilitative to item memory (for the selective effect of semantic association on item memory, see also Saint-Aubin, Guérard, Chamberland, & Malenfant, 2014). In addition, their view posits that

label cuing primarily enhances item memory (for the selective effect of labels on item memory, see also Botvinick & Plaut, 2006, pp. 220-221).

In fact, a classic STM study by Baddeley (1966) demonstrated the detrimental effect of semantic similarity (see also, Crowder, 1979). In Baddeley's study, target words were visually presented to participants throughout the whole session and participants were asked for ordered responses. Thus, Ishiguro and Saito (2020) identified the task in Baddeley (1966) as the serial reconstruction of order task. As the serial reconstruction of order task can be regarded as a measure of order memory (Saint-Aubin & Poirier, 1999b; Whiteman, Nairne, & Serra, 1994), the detrimental effect of semantic similarity demonstrated by Baddeley (1966) is consistent with Ishiguro and Saito's view that semantic similarity is detrimental to order memory. Moreover, it can be said that facilitative effects of semantic association and labeling on item memory are not captured by the serial reconstruction of order task. Accordingly, data of the serial reconstruction of order task would clearly demonstrate the detrimental effect of semantic similarity by separating it from effects of semantic association and labeling. By contrast, it remains unclear whether and how semantic similarity, separated from semantic association and labeling, has effects in the serial recall task, even though the serial recall task has been used as a common STM measure.

1.3. Details of Current Study

Building on the view proposed by Ishiguro and Saito (2020), we made three predictions regarding the semantic similarity effect in an experimental setting that controls for effects of association and labeling with the immediate serial recall task. First, the detrimental effect of semantic similarity would be observed in memory performance data that at least partly reflect order memory. Second, its detrimental effect should be null or weak if memory performance is

evaluated by scoring for item memory. Third, its detrimental effect should be evident in scores that measure order memory in particular. These three predictions can be tested using three scoring methods: correct-in-position scoring (for the first prediction), item correct (for the second prediction), and absolute order errors (for the third prediction). We note that, as far as we know, no studies have demonstrated the detrimental effect of semantic similarity with the serial recall task by correct-in-position scoring except for a review study with meta-regression analysis (Ishiguro & Saito, 2020).

In addition to the attempt to minimize effects by semantic association and labeling, as previous studies of the immediate serial recall have demonstrated a detrimental effect of orthographical word length or the number of letters (Coltheart, Mondy, Dux, & Stephenson, 2004) and facilitative effects of imageability or concreteness¹ (Tse & Altarriba, 2007) and frequency (Hulme et al., 1997), these three variables were factored into the analysis. Age of acquisition (AOA) may not affect immediate serial recall performance but it slows speech rate (Roodenrys, Hulme, Alban, Ellis, & Brown, 1994). Considering the possibility that AOA affects memory performance by slowing speech rate (i.e., a possible mediation effect), we also entered a measure of AOA in the analysis.

¹ As values of imageability and concreteness are highly correlated, these two terms are often used interchangeably. In the present study, we consistently use the term “imageability” to refer to either imageability or concreteness (see also, Tse & Altarriba, 2007).

2. Method

2.1. Participants

In total, 120 participants were recruited online via Prolific Academic Ltd. Referring to a previous study that conducted the immediate serial recall task online (Chubala, Guitard, Neath, Saint-Aubin, & Surprenant, 2019), recruitment criteria for participants were as follows: a) first language was English, b) nationality was UK, USA, or Canada, c) approval rate for past studies on Prolific Academic Ltd. was equal to or more than 90%, d) having no language related disorders, e) not having been diagnosed with cognitive impairment or dementia, f) having normal or corrected-to-normal vision, and g) aged 19 to 30 years old.

Data were not stored correctly for four participants because of a computer malfunction. In addition, two participants did not follow instructions as we intended and answered “+” (i.e., the fixation cross) as their remembered first item at each trial. Therefore, data for the remaining 114 participants were used in the analysis. The mean age of these participants was 24.78 years ($SD = 3.62$, range 19-30). A total of 66 participants reported being women and 47 participants reported being men. One participant responded, “prefer not to say.”

2.2. Stimuli

We selected words and constructed lists of words following three steps. First, we selected 2640 words that were commonly available in affective norms (Warriner, Kuperman, & Brysbaert, 2013), frequency norms (Brysbaert & New, 2009), imageability norms for disyllabic words (Schock, Cortese, & Khanna, 2012), and AOA norms (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012). Second, referring to the database of the English lexicon project (Balota et al., 2007), we adopted 1930 noun words out of the 2640 words. In English, a word can be used in several word classes or part-of-speech classes. For example, “approach” can be used as a noun or

a verb. Here, words that can be used at least as nouns were regarded as noun words. Lastly, using Match software (van Casteren & Davis, 2007), we constructed 100 lists of 6 words (600 words in total). We matched arousal and dominance values, imageability, log frequency, AOA, and word length in the orthographic form but did not match for valence values. Nevertheless, the resultant 100 lists did not differ in the mean values of these variables including valence (all $ps > .17$), implying homogeneity of the lists. Note that all words were disyllabic because we adopted words from imageability norms for disyllabic words (Schock et al., 2012), and thus, word length was controlled for in terms of syllable number.

Although the above-mentioned list construction method was designed to minimize categorical and associative relationships between words in a list, we also checked semantic associations between words in each list. Out of 600 words, 492 words were available as cue words in word association norms (De Deyne, Navarro, Perfors, Brysbaert, & Storms, 2019). For these 492 words, the probability of generating each of the other five words of a list when a word of a list was provided as a cue word (i.e., forward associative strength values) was retrieved from the norms. For 2460 forward associative strength values ($492 \text{ cue words} \times 5 \text{ words of a list}$), 2442 values (99%) were 0 and the mean value was almost 0 (5.44×10^{-5}). Thus, semantic associations in each list were judged to be negligible.

2.3. Procedure

At the beginning of the experiment, participants read a webpage with the consent form and moved to a web-based task only if they agreed to participate in the task. Then, participants were instructed to remember six words at a trial and report them in the order in which the words were presented. If they could not recall a word in the correct order, they were instructed to type

“skip.” After these instructions, they took part in 5 practice trials, which were followed by 25 test trials.

Each trial began with a fixation cross presented for 750 ms, followed by a blank of 250 ms. Then, six words were presented sequentially. Each word was presented for 750 ms with an interstimulus interval of 250 ms. After the offset of the last word, a blank of 250 ms was presented. Then, participants started recalling words in a position-by-position manner. The first page contained a text form in which they typed the word presented first at the trial. If they could not recall the first word, they typed “skip.” Then, they moved to the second page. In total, for a trial, there were six pages asking for words at the six positions. After completion of six responses, the next trial began. For 25 test trials, 25 lists randomly sampled from 100 lists were allocated to each participant. In each trial, presentation positions of words were also randomized across participants (e.g., a word would appear at position 1 for a participant but that word would appear at position 6 for another participant). For practice trials, words that were not used for the test trials were used. The task was completed within about 30 min. Participants received 4.5 British pounds for their participation.

2.4. Dissimilarity Index

Referring to Ishiguro and Saito (2020), we define semantic dissimilarity as *distance from the centroid* in a semantic space. Our assumed semantic space has three dimensions of valence, arousal, and dominance because these affective dimensions are thought to be major dimensions in semantics (Hollis & Westbury, 2016; Osgood & Suci, 1955; for detailed discussion, see Ishiguro and Saito, 2020). Words are represented as points in this three-dimensional semantic space. For each list, the centroid is a point that has the mean value for the six words’ valence values, the mean value for their arousal values, and the mean value for their dominance values.

An item's distance from the centroid refers to the Euclidean distance from the centroid to a point of the item. As the centroid is an averaged or blended point in a given list, the distance from the centroid of a word corresponds to the semantic dissimilarity of that word within a list.

3. Results and Discussion

3.1. The Validity of a Web-based Task and the Quality of Data

Although the validity of web-based cognitive tasks has been confirmed (Crump, McDonnell, & Gureckis, 2013), it is desirable to check the quality of data in individual studies (Germiné et al., 2012). As a way of assessing data quality, we examined whether our data replicated benchmark findings established by traditional laboratory experiments. Specifically, we targeted a) *patterns of the serial position curve* and b) *locality constraint of transposition errors* as benchmarks. For the serial position curve, a strong primacy effect and a weak recency effect have been reported in the immediate serial recall task: the primacy effect is typically large in size, spanning over several early items, while the recency effect is usually small and limited to the last one or two items (e.g., Jahnke, 1963). Locality constraint refers to a constraint that order errors follow, by which the probability of recalling an item wrongly decreases as the distance between the input position of the target item and the input position of that wrongly recalled item increases (Henson, Norris, Page, & Baddeley, 1996). For example, in an attempt to recall an item presented at position t at output position t , a wrongly recalled item is more likely to be an item presented at position $t + 1$ or $t - 1$ than an item presented at position $t + 2$ or $t - 2$.

Figure 1 represents transposition gradients of our data. Clusters are grouped by output position. Within a cluster, six bars indicate response proportions or recalling probabilities of each item presented at input positions 1-6.

Figure 1. Transposition gradients from our web-based immediate serial recall task. Response proportions were clustered by output positions 1-6. Within each cluster, six bars represent items' input positions 1-6. As the task used an open set of items (instead of a closed set) and allowed the response of "skip," the sum of response proportions in a cluster does not need to equal 1.0.

The peaks of each cluster correspond to correct recall proportions in our data: a strong primacy effect and relatively weak recency effect are evident. In addition, patterns of transposition gradients follow locality constraints: items adjacent to the target item are recalled more frequently than far items in terms of input position. We note that our data appear to show

an asymmetry of transposition gradients or, more specifically, a tendency of forward movement errors over backward movement errors. Although a tendency of forward movement errors would not be an established finding, Haberlandt, Thomas, Lawrence, and Krohn (2005) reported a tendency of forward movement errors, consistent with the present study's data.

Given that our data replicated benchmark findings of primacy, recency, and transposition error patterns, and that we set an acceptance rate for recruitment, we judged the quality of our data to be acceptable and that the validity of our web-based task was confirmed.

3.2. Memory Performance at an Item Level

For a fine-grained analysis of the semantic similarity effect, we targeted memory performance at an item level. Dependent variables are a) correct-in-position scores, b) item correct scores, and c) absolute order errors. As for correct-in-position scores, when an item was recalled at its correct position, "1" was assigned to that item. Otherwise, "0" was assigned to that item. For item correct scores, when an item was recalled at a trial in which that item was presented, regardless of its position, that item received "1." Otherwise, "0" was assigned to that item. Absolute order errors refer to whether items were recalled at wrong positions, which was calculated by subtracting correct-in-position from item correct scores (i.e., an order error = item correct - correct-in-position score). We suppose that correct-in-position scores reflect both item and order memory while item correct scores primarily reflect item memory. Absolute order errors are thought to reflect errors of order memory.

For each dependent variable, we used a mixed-effects logistic regression model with variables of fixed effects being a) input position, b) word length, c) imageability, d) log frequency, e) AOA, and f) distance from the centroid to test whether these variables affected the recalling probability of an item. As correlations between semantico-lexical values of the selected

600 words were moderate to weak (absolute values of Pearson's correlation coefficient r s range from .01 to .52), multicollinearity was unlikely to occur in an item-level analysis. We also set participant, list, and word as variables of random effects with an assumption that words were nested within lists.

Our primary interest was the fixed effect of distance from the centroid but we recognized the possibility of random slopes for distance from the centroid within each participant and/or stimulus (i.e., list and word). In other words, the effect of distance from the centroid would vary depending on each participant and/or stimulus. Thus, for each of the three types of scores (i.e., correct-in-position, item correct, and absolute order errors), we compared four models: a) a model with only random intercepts, b) a model with random intercepts and random slopes for each participant, c) a model with random intercepts and random slopes for each stimulus, and d) a model with random intercepts and random slopes for both of each participant and stimulus. Model selection for mixed models by using the Akaike information criterion (Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017) favored a simple model with only random intercepts for three types of scores. Therefore, we reported the results of the simple model below. We note that the statistical software we used (i.e., R) provided “boundary (singular) fit” warnings for several of the complex models, which would also justify the selection of a simple model. As we reported raw data and scripts for the analysis on the first author's GitHub repository (<https://github.com/grocio/semsim-stm-exp>), modelers can also test alternative models.

3.2.1. Correct-in-position scores. Table 1 shows the results of a logistic regression model for correct-in-position scores. As the serial position curve shows the strong primacy effect for the first position, negative effects for positions 2-6 are interpreted as a disadvantage relative to the first position. A negative effect of word length ($z = -6.32, p < .001$) and positive effects of imageability ($z = 4.01, p < .001$) and frequency ($z = 5.95, p < .001$) indicated their effects on STM. AOA did not reach statistical significance ($z = 0.28, n.s.$). More importantly, distance from the centroid had a positive effect ($z = 2.02, p < .05$), indicating that the recalling probability of an item increased as the distance between that item and the centroid of a list increased. As we assumed that the distance on a semantic space indicated semantic dissimilarity, the results support the detrimental effect of semantic similarity on STM (or the facilitative effect of semantic dissimilarity).

Table 1

Results of a Logistic Model for Correct-in-Position Scoring Data

	Estimate	SE	z value	p value	
Intercept	1.13	0.31	3.63	< .001	***
Position 2	-0.85	0.06	-13.09	< .001	***
Position 3	-1.21	0.06	-18.81	< .001	***
Position 4	-1.92	0.07	-29.24	< .001	***
Position 5	-2.72	0.07	-38.77	< .001	***
Position 6	-2.36	0.07	-34.83	< .001	***
Distance from centroid	0.07	0.03	2.02	.044	*
Word length	-0.14	0.02	-6.32	< .001	***
Imageability	0.09	0.02	4.01	< .001	***
Frequency	0.28	0.05	5.95	< .001	***
AOA	0.00	0.01	0.28	.780	

Note. Intercept partly reflects the effect of the first position. * $p < .05$. *** $p < .001$

3.2.2. Item correct scores. As a measure of item memory, item correct scoring was also used. Table 2 shows the results of a logistic regression model for item correct scoring. Similar to results for correct-in-position scoring in the previous subsection, position (see positions 2-5), word length ($z = -5.93, p < .001$), imageability ($z = 3.70, p < .001$), and frequency ($z = 6.34, p < .001$) had significant effects on item correct scores while AOA did not ($z = 0.16, n.s.$). Nevertheless, distance from the centroid did not reach significance ($z = 0.88, n.s.$). Although reasoning based on a lack of statistical significance needs caution, the contrast between a significant effect of distance from the centroid on correct-in-position scoring (Table 1) and its non-significant effect on item correct scores (Table 2) supports that semantic similarity affects order memory but not item memory.

Table 2

Results of a Logistic Model for Item Correct Scoring Data

	Estimate	SE	z value	p value	
Intercept	1.28	0.30	4.35	< .001	***
Position 2	-0.52	0.07	-7.79	< .001	***
Position 3	-0.80	0.07	-12.19	< .001	***
Position 4	-1.54	0.07	-23.58	< .001	***
Position 5	-2.40	0.07	-35.33	< .001	***
Position 6	-2.22	0.07	-33.22	< .001	***
Distance from centroid	0.03	0.03	0.88	.380	
Word length	-0.13	0.02	-5.93	< .001	***
Imageability	0.08	0.02	3.70	< .001	***
Frequency	0.28	0.04	6.34	< .001	***
AOA	0.00	0.01	0.16	.872	

Note. Intercept partly reflects the effect of the first position. * $p < .05$. *** $p < .001$

3.2.3. Absolute order errors. The contrast between correct-in-position scores and item correct data suggests that semantic (dis)similarity defined by distance from the centroid affects order memory. As a direct index for order memory, absolute order errors are focused on here. It should be noted that observations of absolute order errors can be affected by item memory because absolute order errors cannot be observed unless items are recalled: recalling more items would lead to an increase of observations of absolute order errors. An analysis of item correct scores in the previous subsection, however, does not support that distance from the centroid increases item memory. Therefore, an effect of distance from the centroid on absolute order errors in our data is assumed to reflect its effect on absolute order memory appropriately.

Table 3 shows the results of a model for absolute order errors. Two important patterns are recognized. First, distance from the centroid decreases absolute order errors ($z = -2.41, p < .05$). Second, all of the other semantico-lexical variables of word length ($z = 1.21, n.s.$), imageability ($z = -0.98, n.s.$), frequency ($z = 0.51, n.s.$), or AOA ($z = -0.27, n.s.$) did not reach significance. Comparison of these results and those of a model for item correct scores would suggest that distance from the centroid selectively affects order memory while word length, imageability, and frequency selectively affect item memory.

Table 3

Results of a Logistic Model for Absolute Order Error Scoring Data

	Estimate	SE	z value	p value	
Intercept	-3.86	0.41	-9.33	< .001	***
Position 2	1.37	0.13	10.17	< .001	***
Position 3	1.62	0.13	12.23	< .001	***
Position 4	1.55	0.13	11.67	< .001	***
Position 5	1.16	0.14	8.44	< .001	***
Position 6	0.65	0.15	4.43	< .001	***
Distance from centroid	-0.11	0.04	-2.41	.016	*
Word length	0.04	0.03	1.21	.228	
Imageability	-0.03	0.03	-0.98	.328	
Frequency	0.03	0.06	0.51	.610	
AOA	0.00	0.02	-0.27	.788	

Note. Intercept partly reflects the effect of the first position. * $p < .05$. *** $p < .001$

4. General Discussion

STM theories generally assume a detrimental effect of similarity, which is corroborated by ample evidence for detrimental effects of phonological, tonal, visual, and social trait similarity (e.g., Ishiguro & Saito, 2019; Saito et al., 2008; Williamson et al., 2010). Semantic similarity, however, has been regarded as facilitative of STM (e.g., Saint-Aubin & Poirier, 1999a). Given that the facilitative effect of semantic similarity is inconsistent with STM theories and detrimental effects of other types of similarity, it is theoretically and empirically important to test whether semantic similarity is facilitative or detrimental of STM.

Ishiguro and Saito (2020) suggested that the oft-reported semantic similarity advantage is attributable to facilitative effects by confounding factors of semantic association and additional retrieval cues (cf. Saint-Aubin et al., 2005; Tse, 2009), but semantic similarity per se is

detrimental to STM. According to this view, semantic similarity should exhibit a detrimental effect on STM if controlling for effects of semantic association and additional retrieval cues.

In the present experiment, to minimize the effects of semantic association and additional retrieval cues, we randomly selected words regarding associative or categorical relationships between words. Experimental results of correct-in-position scores from the immediate serial recall task indeed supported the view by Ishiguro and Saito (2020): semantic similarity impaired STM performance. Although correct-in-position scoring is a common scoring method for the immediate serial recall task, it would reflect a mixture of both item and order memory (Nairne & Kelley, 2004; Saint-Aubin & Poirier, 1999b). To investigate how semantic similarity impairs STM in terms of the item versus order memory distinction, we also utilized two additional scoring methods (i.e., item correct and absolute order errors). Results suggested that semantic similarity increased absolute order errors but did not affect item correct scores (i.e., the null effect), which is in line with the view that semantic similarity is detrimental to order memory but neutral to item memory. The presence or absence of effects of semantico-lexical variables on item correct scores and order errors are complementary to semantic similarity effects. Specifically, the null effect of semantic similarity for item correct scores would not be attributed to the insensitivity of item correct scoring since the effects of word length, imageability, and frequency for item correct scores are evident. In addition, for order errors, an effect of semantic similarity with a lack of statistical evidence for effects of word length, imageability, and frequency supports a view that semantic similarity leads to confusions between items.

Considering the findings by three different scoring methods, we concluded that the effect of semantic similarity is detrimental to STM and the locus of its detrimental effect is on order memory but not on item memory. As the present study's findings are consistent with three

predictions derived from a view suggested by a meta-analytic review (Ishiguro and Saito, 2020), we suggest that the present study supports this view.

4.1. Effects of Semantico-Lexical Factors on Item and Order Memory

Our primary interest was semantic similarity and factors of orthographical word length, imageability, and frequency, which are known to influence correct-in-position scores, were controlled for. Nevertheless, it would be valuable to consider their effects on item and order memory. Although orthographic word length has been often confounded with phonological word length in past studies' experimental settings (e.g., Baddeley, Thomson, & Buchanan, 1975), Coltheart et al. (2004) aimed to separate these two types of word length and demonstrated significantly higher item recall for four-letter monosyllabic words than for six-letter monosyllabic words. Furthermore, they reported identical percentages of order errors for four-letter and six-letter monosyllabic words (in their Table 1). Taken together, their findings are consistent with our findings, showing a detrimental effect of orthographic word length on item memory and its null effect on order memory. As for imageability and frequency effects on item and order memory, previous studies have provided coherent results of these facilitative effects on item memory and mixed results for these effects on order memory. For example, Tse and Altarriba (2007) and Walker and Hulme (1999) showed an effect of imageability on item memory and its null effect on order memory, whereas Allen and Hulme (2006) showed that imageability had facilitative effects on both item and order memory. Likewise, while existing studies seem to converge in supporting the facilitative effect of frequency on item memory, some studies reported its facilitative effect on order memory (e.g., Hulme, Stuart, Brown, & Morin, 2003; Tse & Altarriba, 2007) but other studies did not (e.g., Allen & Hulme, 2006; Poirier & Saint-Aubin, 1996).

To recapitulate, the literature indicates that, despite the ambiguity in the effects of semantico-lexical factors on order memory, effects of these factors on item memory are robust. These effects on item memory sharply contrast with null results of the semantic similarity effect on item memory demonstrated by the current study.

4.2. Affect and Semantics

The distance from the centroid of a given word in the valence-arousal-dominance space may correspond to the emotionality of that word. This is because affectively loaded words in terms of valence, arousal, and dominance tend to have large distances from the centroid. Thus, a positive effect of the distance from the centroid, which we assume reflects semantic dissimilarity, can also be viewed as an effect of emotionality. We note that affect is not necessarily separable from semantics given that activating affective information of a word is a form of activating semantic information of that word (Lambon Ralph, Jefferies, Patterson, & Rogers, 2017; Martin, 2016) and that several STM researchers indeed consider affective information as a part of semantics (Majerus & D'Argembeau, 2011; Monnier & Syssau, 2008). Importantly, how the distance from the centroid (either called “emotionality” or “semantic dissimilarity”) influences memory performance should be considered. We suggest that the null results of the distance from the centroid’s effect on item memory do not fit well with a straightforward explanation that affectively loaded words draw attention and enhanced attention leads to better memory for affectively loaded words. By contrast, demonstration of the facilitative effect of the distance from the centroid on order memory supports that affectively dissimilar words on a given list are less likely to be confused with other words. Considering the patterns of influence of the distance from the centroid on item versus order memory, our results would imply the semantic

(dis)similarity effect in terms of semantics and the affective (dis)similarity effect in light of affect.

4.3. Implications for Memory Models

Our findings regarding the semantic similarity effect, along with findings from STM studies on semantic factors (Campoy, Castellà, Provencio, Hitch, & Baddeley, 2015; Jefferies, Hoffman, Jones, & Lambon Ralph, 2008; Nishiyama, 2014; Walker & Hulme, 1999), imply the importance of a semantic factor in STM. A unique contribution of the current study is that it demonstrated the detrimental effect of semantic similarity. As far as we know, this is the first study that demonstrated the detrimental effect of semantic similarity in the immediate serial recall task by using correct-in-position scoring. In addition to its novelty, its demonstration of the detrimental effect of semantic similarity has implications for STM models because detrimental effects of similarity are key findings in modeling STM. For instance, the detrimental effect of phonological and visual similarity have been regarded as evidence for phonological and visuospatial stores in working memory frameworks (Baddeley, 1986; Baddeley & Logie, 1999; see also, Camos & Barrouillet, 2014). Our findings of the detrimental effect of semantic similarity would imply a semantic store, the functions of which are similar to those of phonological and visuospatial stores, or a general process acting for a variety of information types. Now that a semantic effect comparable to phonological and visual effects has been observed, it is desirable to compare and synthesize findings regarding semantic, phonological, and visual maintenance in future studies.

Declarations of Interest: The authors report no conflicts of interest.

Open Practice: For reproducibility and transparency, anonymized data of memory performance, materials, and scripts used in the analyses are reported in the first author's GitHub repository (<https://github.com/grocio/semsim-stm-exp>).

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