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RESEARCH ARTICLE

Dual-task performance of speech and motor skill: verb generation facilitates grasping behaviour

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Abstract
Pronouncing nouns or verbs while grasping distinctly alters movement. Changes in hand speed and final position occur according to the meaning of the words spoken. These results are typically found when executing a single movement paired with a single word. For example, pronouncing the word 'fast' increased the speed of the hand when reaching to grasp. Our objective was to compare how verb and noun fluency tasks interact with grasping behaviour in a grasp-to-construct task. Because previous imaging research shows that verb and noun production activates distinct neural areas, we reasoned that grasping outcomes would differ according to the category of word produced by participants. Specifically, we hypothesized that verb pronunciation would distinctly affect grasping behaviour compared to producing nouns. We recruited 38 young adults who performed a grasp-to-construct task and two different verbal fluency tasks. Participants completed each task (grasp, verb fluency, and noun fluency) separately as control conditions, and the grasping and each speaking task simultaneously for dual-task conditions. We found that during the dual-task condition, when generating nouns and grasping, participants made significantly more grasping errors (inaccurate grasps) compared to the control and verb dual-task conditions. Moreover, our results revealed a relationship between the number of verbs generated and grasping performance. Participants who generated more verbs were faster and more accurate during the motor component of the dual-task condition. This relationship was not observed when nouns were produced, indicating a unique relationship between verb production and functional grasping. The result is a facilitation effect, diminishing the negative outcome on motor control associated with increased cognitive load (as observed during noun pronunciation).

Keywords Grasp-to-construct · Verb generation · Noun generation · Facilitation · Dual task · Speech production

Introduction

There is a large body of research that reveals how language in its various forms [processed and spoken (syllables, single words, sentences)] influence different types of manual movement [Vainio et al. 2013; Vainio et al. 2015; (for a review, see Garcia and Ibanez 2016)]. A focus of this research is to investigate how the meaning of speech can distinctly alter grasping performance. An example comes from a kinematic study by Fargier et al. (2012), where participants produced either action- or non-action-related words. The authors demonstrated that generating verbs (action words) while executing grasping actions resulted in higher wrist peak velocity and greater initial hand acceleration. Other examples include studies where the participant's manual grip force increased while uttering verbs related to grasping (da Silva et al. 2018; Frak et al. 2010); and nouns associated with different grasps; precision (thumb and index finger) or power (whole-hand) altered the shape of the hands to mirror the pronounced word, as opposed to the physically grasped object (Glover et al. 2004). These examples suggest an interdependent relationship between motor control and language—the meaning or semantics of speech can be reflected during action execution. This relationship is often presented as evidence for the theory of embodied cognition. This theory suggests that sensory information is processed in the context of a body that can interact with the world, which gives rise to our ability to understand our environment (Casado et al. 2018; Garcia and

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Ibanez 2016; Tomasino et al. 2008; Wilson 2002). Embodied cognition explains the outcome of these dual-task studies in that participants receive sensory input (i.e. visual or auditory) by reading or hearing the word, which then gets translated into motor output (i.e. speech). The word (e.g. "apple") as an input, output, or both, is then associated with concrete characteristics of the object (i.e. medium, spherical, edible object), which we regularly manipulate and interact with. The association between the word and the features of the object learned through physical interactions is possibly what results in changes to simultaneous (i.e. saying apple but grasping a block) but unrelated motor execution. Given this theory and this application, it follows that pronouncing a word like "grasp" which actually describes the executed action alters the concurrent movement of the hand when grasping objects (Fargier et al. 2012). Worth noting is that in the previous studies, participants generally executed a single action, whether a grasp or simple contraction of the fingers, while producing (or processing) a single word. These sterile setups enable a clearer understanding of the interaction between word meaning and grasping, but do not reflect everyday life. If embodied cognition is an ever present process, then when we are speaking and grasping during a complex situation, there should still be evidence of selective alteration of action during more natural speech. An example would be when executing a series of actions and generating self-selected speech, as in this study.

To investigate the interaction during the execution of more ecologically relevant, manually, and cognitively demanding tasks, we examined verbal fluency (multiple word generation) during a continuous reaching and grasping paradigm (building with Lego™). Mirroring previous studies, we selected both verb- and noun-generation tasks as research suggests that while each word type activates identical neural areas responsible for the motor control of speech (Shapiro et al. 2006), there are distinct neural patterns associated with the processing/production of each speech category. Verb processing is associated with increased activation relative to noun processing in the left primary motor cortex (Oliveri et al. 2004), distinct activation in the left superior parietal lobule, the left prefrontal cortex (Shapiro et al. 2006), and the left inferior parietal cortex (Peran et al. 2009; Warburton et al. 1996). Conspicuously, all these areas are key for action execution. In contrast, non-action noun words show unique activation in the left inferior temporal lobe compared to verbs (Shapiro et al. 2006). Lesion studies in particular highlight the importance of the temporal lobe in noun processing, as temporal lobe lesions result in unimpaired speech, with the exception of noun production (Damasio and Tranel 1993). In addition to association with distinct neural areas, word fluency tests are ideal for this study, because they are widely used in dual-task studies (Fuller et al. 2013; Patel et al. 2014; Silveri et al. 2018), and have demonstrated validity through high test/retest reliability (Harrison et al. 2000; Woods et al. 2005).

Based on the documented neural distinctions between verb and noun production and their effects on motor control, we predicted distinct behavioural outcomes between word generation for each grammatical category while engaged in a complex motor task. For this task, we distributed Lego™ blocks across a tabletop, which participants grasped and used to replicate different models, constructing each as quickly and accurately as possible (Stone et al. 2013; Stone and Gonzalez 2015). We predicted that performing either speech condition (verb or noun generation) during the motor task would result in increased construction time, and/or increased grasping errors, as well as a decrease in number of pronounced words compared to the control word generation/construction condition. This prediction is based on the cognitively demanding nature of both tasks, as previous studies which required production of multiple motor actions paired with a cognitive task (i.e. randomly generating numbers while tapping different buttons) typically result in decreased performance of one (Albinet et al. 2006) or both of the tasks (Gunduz Can et al. 2017; Weigelt et al. 2009). An additional prediction was that nouns would interfere more than verbs during the motor task because of their unrelated nature. Generating verbs could in fact facilitate grasping behaviour because of the implicit association between verbs and action.

Materials and methods

Participants

Thirty-eight undergraduate students (20 females, 18 males; 24 right handers) participated in the experiment for course credit. Before beginning the study, all participants provided voluntary informed consent. We conducted this study with approval from the University of Lethbridge Human Research Ethics Committee (#002-2016).

Materials

Participants sat centered in front of a table (122 cm wide, 122 cm long and 74 cm tall). We filmed all tasks with a digital video camera (JVC HD Everio®) setup across the table from the seated participant (approximately 160 cm away). Lego™ blocks were used to create 12 20-piece 3-dimensional models (see Fig. 1b for examples).

Procedure

All the following sequences were counterbalanced and completed in a pseudorandom order for each participant.

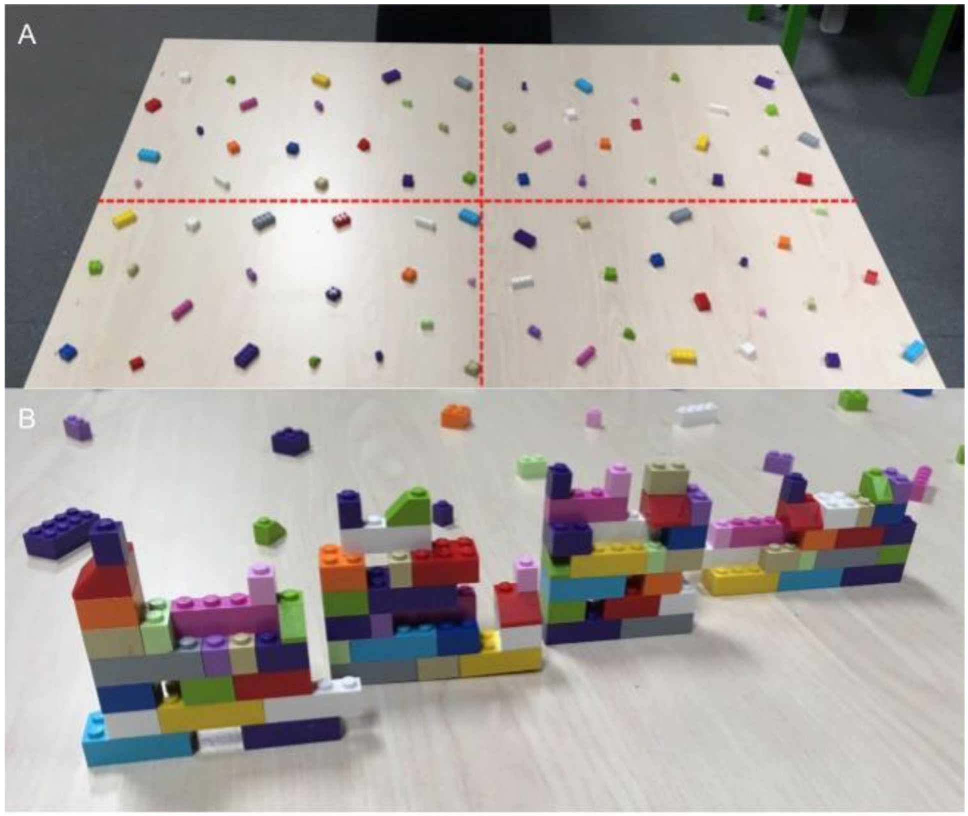

Fig. 1 Experimental setup for the grasp-to-construct tasks. **a** Each of the four quadrants separated by the imaginary dashed line contains an identical set of 20 pieces. **b** Example of models presented to participants one at a time, either during the control or dual-task conditions

Control conditions

Control-speech

Each participant performed two word-generation tasks (a verb fluency task and a noun fluency task). Following previous studies (Zhao et al. 2013; Shao et al. 2014), we required participants to spend a minute producing as many verbs which could typically be performed in a room (similar to an action fluency task) and as many nouns as possible that were relevant to the provided category (also known as a category fluency task). Before beginning each task, we provided an example category/room and potential words to the participant. The example room for generating verbs was the word 'garage' and appropriate examples could be grasping, constructing, parking, hammering, etc. The example for nouns was the category 'clothes', and appropriate associated nouns could be shirt, blouse, sweater, socks, etc.

For verb-generation tasks, participants received the additional instruction that all verbs generated must end in "ing". We included this rule as it appeared to help participants better understand and select only verbs while generating words. Each participant completed the noun- and verb-generation task twice (consecutively) using two of six randomized and counterbalanced category/rooms. We used the remaining eight noun and verb word stimuli (four categories for nouns, four rooms for verbs) during the dual-task conditions, verb-construct and noun-construct (see Table 1 for categories).

Control-motor

Procedures for the grasp-to-construct task were similar to those found in Stone et al. (2013) and Gonzalez et al. (2014a). To set up the task, 20 identical blocks (matching

Table 1 List of stimuli used to generate verbs and nouns with average (standard deviation) number of words generated per minute per condition

Room/category	Control	Dual task
Kitchen	18.40 (±4.36)	11.88 (±3.56)
Gymnasium	18.36 (±7.41)	11.28 (±4.89)
Restaurant	18.11 (±5.13)	11.48 (±3.98)
Art Room	15.87 (±3.66)	9.08 (±2.66)
Bathroom	15.08 (±4.96)	9.74 (±3.22)
Party	13.54 (±4.15)	10.00 (±4.10)
Animals	27.33 (±6.36)	15.35 (±5.31)
Sports	18.75 (±4.96)	15.71 (±5.40)
Fruits	18.33 (±5.13)	14.39 (±3.74)
Desserts	17.63 (±4.36)	11.26 (±4.25)
Electronics	14.56 (±4.89)	12.35 (±3.00)
Toys and games	13.56 (±3.55)	10.23 (±3.45)

in shape and colour) were randomly distributed within 4 equal-sized quadrants of the tabletop, resulting in a total of 80 blocks (Fig. 1a). During the task, the researcher placed 1 model (made up of 20 blocks) across the seated participant (as per Stone et al. 2013), and instructed them to assemble the model as quickly and accurately as possible, creating a replica (i.e. same coloured and shaped blocks) of the model. Additional instructions included keeping both hands on the table, grasping one block at a time, and not touching the model, as all blocks were visible from the provided position. In the control condition (no dual task), participants built four models in a row, starting the next model immediately after completing the previous (see Fig. 1b). If the participant built each model accurately, no blocks were replaced on the table, and after each model, there were 20 fewer blocks present. After the fourth and final model was complete, no blocks were left on the table. The researcher presented the models in a pseudorandom order.

Experimental condition

Dual task (verb-construct/noun-construct)

During the dual-task condition, participants attempted to complete the speech and grasp-to-construct tasks at the same time. Each participant completed the previously described tasks with a few adjustments. Participants produced as many words relevant to the category (verb or noun) as possible while building one of four models from the blocks on the tabletop. At the start of the dual-task condition, we provided a block model and a category or room, and instructed the participants to produce as many appropriate words while still replicating the model quickly and accurately. After completing the model, the experimenter presented the next model and provided the participant with a new category/room (depending on the condition). The participant would again generate as many words suited to that category while replicating the different model. This continued until the participant completed four models, and typically used all block pieces present on the table. If the participant completed the noun-generation task first, they would repeat another dual-task condition, assembling four more models (new) but instead generated verbs. During this task, the remaining eight categories and rooms were used.

Data processing and analysis

All video recordings were analyzed offline. We used several different variables for analysis. First, for the control word-generation tasks (where each participant had a minute to produce as many verbs/nouns), we calculated the average number of words per minute per part of speech (verb or noun) by adding the total number of words generated during each category and dividing by two. This is because each participant completed two different categories for both verbs and nouns. During the dual-task conditions, participants generated words during the entire time they constructed models, and as a result, word generation lasted longer than a minute. To remain consistent between the control and experimental trials, we calculated the total words spoken in the first 60 s and ignored any words generated after. As a precaution, we completed an analysis comparing the difference between the average number of words generated a) during the first 60 s of the dual-task conditions; and b) per minute (some participants took up to 3 min to complete the task). Findings are included in the results. Identical to the control, we averaged the total words per minute across the four trials, resulting in a single word per minute average for the dual task.

For the grasping conditions, the grasping errors were defined as any instance the participant selected an incorrect block while constructing the model. We measured this by counting the number of times participants picked up a block and did not immediately use it in the model (i.e. grasped the block, then placed it back down to grab a different block). There were three different grasping conditions (control, dual task (verb), dual task (noun)), and during each, the participant constructed four models. Construction time was defined as the total amount of seconds required to build the four models within the set condition. Because the conditions were counterbalanced, changes in construction time and/or grasping errors could be interpreted in the following ways: (a) improved performance (faster building time and/or lower accuracy), (b) decreased performance (slower building time and/or better accuracy) or, (c) no change in performance. Differences between the noun and verb generation can be understood in the same way.

We defined one final measure to quantify the distinct interactions between the verb-construct and the noun-construct conditions. We calculated the percent change between the dual-task and the control conditions for verbs and nouns per dependent variable (i.e. number of nouns generated in noun-construct/nouns generated in control condition $\times$ 100). These values were calculated for word generation, construction time, and construction errors.

To perform the data analysis, we used SPSS statistics 24.0 for Windows (SPSS Inc., Chicago, IL, USA) and RStudio (RStudio team, 2016). A statistical significance level of $\alpha = 0.05$ was set for each analysis.

Results

Due to the previous reporting of sex differences in verbal fluency tasks (Kolb and Whishaw 2001, 2009), we initially included sex as a variable in our analyses. We ran additional analyses with handedness as a between factor to determine if any differences existed between left and right handers, as shared lateralization of speech and right-hand motor control (Kolb and Whishaw 2009) may affect a speech/grasping relationship. No significant main effects or interactions with sex or handedness were found. Thus, all data presented below are collapsed across both sex and handedness.

Word generation

To determine how to best control for differences in time given for word generation between the control condition (60 s) and dual-task conditions (range 57–190 s), we completed several comparisons. On average, participants took 92.84 (SD 17.52) seconds to finish building during the verb-construct condition, and 92.12 (SD 22.24) seconds to complete models during the noun-construct task, a non-significant difference [$t(38) = -0.36$, $p = 0.72$]. Using a paired-sample t test, we did find a significant difference between the average words produced in the first 60 s, compared to the average word per minute (WPM) generated over the whole time for both verbs [$t(38) = 10.14$, $p < 0.001$] and nouns [$t(38) = 9.77$, $p < 0.001$]. For verb-construct, the first minute had a higher word-generation rate ($M = 10.42$, SD 3.10) than the average WPM ($M = 8.87$, SD 3.27). For noun-construct, it was the same finding: the first minute had a higher word-generation rate ($M = 12.31$, SD 3.17) than the average WPM ($M = 10.18$, SD 3.24). Given the purpose of the study to compare dual-task effects, we opted to use the words generated in the first 60 s to maintain a straightforward comparison with the control condition.

A repeated-measures ANOVA was conducted with two factors: condition (control, dual task) and grammatical class (verbs, nouns). Results revealed a significant main effect of condition [$F_{(1, 37)} = 140.96$; $p < 0.0001$; $\eta^2 = 0.79$], a significant main effect of grammatical class [$F_{(1, 37)} = 19.43$; $p < 0.0001$; $\eta^2 = 0.34$], but no significant interaction [$F_{(1, 37)} = 0.01$; $p = 0.92$; $\eta^2 = 0.00$] (see Fig. 2). There were significantly more words generated during the control condition ($M = 17.65$; SD 0.62) compared to the dual-task condition ($M = 11.46$; SD 0.44), and individuals produced significantly more nouns ($M = 15.51$; SD 0.50) than verbs ($M = 13.60$; SD 0.54). Note that there were significantly more words generated in the control condition compared to the dual-task condition, and across both conditions participants generated significantly more nouns than verbs (see Table 1 for means).

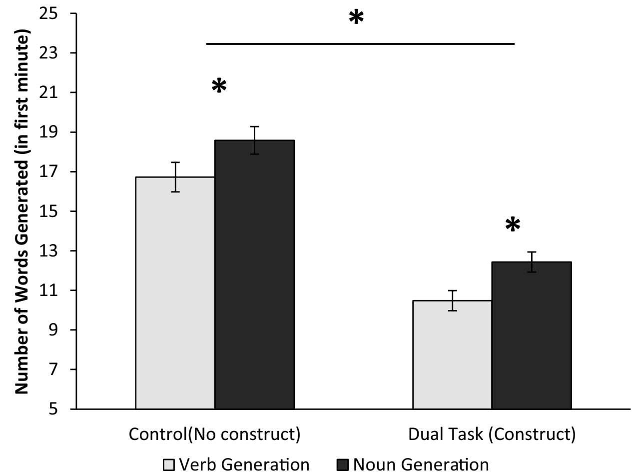

Fig. 2 Average number (and standard error) of words generated by participants according to condition (control and dual task) and grammatical class (verbs and nouns)

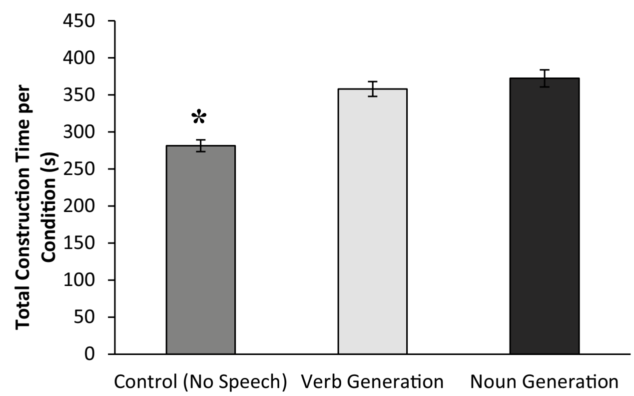

Fig. 3 Average and standard error (in seconds) for construction time observed in the grasp-to-construct task by condition (control-construct, verb-construct, and noun-construct). Note that the control-construct condition was performed significantly faster when compared to the other two conditions

Grasp-to-construct

Construction time

A repeated-measures ANOVA was conducted with grasp-to-construct condition (Control-motor, verb-construct, noun-construct) as the independent variable and construction time as the dependent variable. Mauchly's test for sphericity was not significant resulting in the use of the Huynh–Feldt correction. Results revealed (see Fig. 3) a significant main effect of grasp-to-construct condition [$F_{(1.87, 69.09)} = 64.54$; $p < 0.0001$; $\eta^2 = 0.64$]. Follow-up pairwise comparisons with a Bonferroni correction revealed that the control-motor condition (281.30 ± 8.00) was performed faster than the verb-construct condition (357.82 ± 10.02; $p < 0.001$) and the noun-construct condition (372.82 ± 11.71; $p < 0.001$). Verb-construct and noun-construct did not differ from each other ($p = 0.32$).

Grasping errors

Non-normal data resulted in the use of a Friedman's Test to determine whether concurrent word production resulted in a change in grasping errors between the control-motor ($M=5.50$; SD 0.61), verb-construct ($M=5.37$; SD 0.72), and the noun-construct conditions ($M=8.63$; SD 1.27). The Friedman's Test was significant χ^2 (2, $N=38$) = 13.21, $p<0.001$. Specifically, grasping errors during noun-construct were significantly higher than Control condition ($p=0.04$) and verb-construct grasping errors ($p=0.002$). There was no difference between control and verb-construct grasping errors ($p=1.00$) (Fig. 4).

Correlations

Control

To investigate the possible relationship among construction time and grasping errors during the grasp-to-construct condition, we used a correlation (Kendall's tau-b) analysis. There was no significant correlation between construction time and grasping errors ($r=0.12$; $p=0.32$).

Verb-construct

To investigate the possible relationship among verb-generation, construction time, and grasping errors, a correlation (Kendall's tau-*b*) was conducted on these variables. Table 1 shows a positive correlation between dual-task construction time and grasping errors ($r=0.32$; $p=0.006$). The longer the individual took to construct the model while generating verbs, the more grasping errors they made. There was a negative correlation between construction time and verb generation ($r=-0.31$; $p=0.007$), indicating the faster the individual assembled the model, the more verbs they generated. There was also a negative correlation between grasping errors and verb generation ($r=-0.29$; $p=0.014$). The fewer grasping errors the participant made, the more verbs generated.

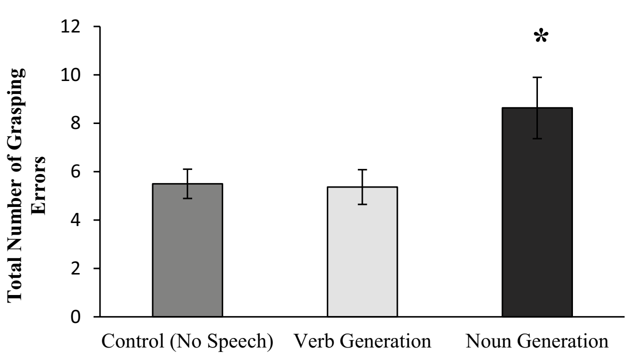

Fig. 4 Average and standard error for grasping errors observed in the grasp-to-construct task by condition (Control, verb-construct, and noun-construct). Note that the only the dual-task (noun) condition resulted in significantly more grasping errors when compared to the other two conditions

Noun-construct

To investigate the possible relationship among noun generation, construction time and grasping errors during simultaneous execution, we conducted a correlation analysis (Kendall's tau-*b*). Table 2 shows a positive correlation between construction time and grasping errors ($r=0.32$; $p=0.007$), suggesting that the longer the participant took to assemble while generating nouns, the more grasping errors they made (similar to verbs). There was no significant correlation between construction time and noun generation ($r=-0.14$; $p=0.21$), or between grasping errors and noun generation ($r=-0.07$; $p=0.57$).

Regression

To determine the extent of the relationship between the variables in the dual-task verb condition, we conducted a multiple linear regression. Multicollinearity and homoscedasticity were low, indicating the data can be appropriately fitted into a regression. We created a model to determine if verbal fluency could be predicted by a participant's construction speed and/or accuracy. The analysis was significant; both construction time and grasping errors explained 19% of the variance in number of verbs generated ($r^2=0.19$, $F_{(2, 35)}=5.23$, $p=0.01$). Construction time was a weak predictor, approaching significance ($\beta=-2.02$, $p=0.05$), while grasping errors were not significant ($\beta=-1.67$, $p=0.10$).

Table 2 Correlation matrix of dual-task variables

	Grasping errors	Word generation
Verb production		
Construction time (Verb construct)	0.323**	– 0.309**
Grasping errors (Verb construct)		– 0.291*
Noun production		
Construction time (Noun construct)	0.315**	– 0.142
Grasping errors (Noun-construct)		– 0.067

The correlation coefficients between dependent variables from the verb-construct and noun-construct conditions separated according to the word-class generated (verbs or nouns)

*Correlation is significant at the 0.05 level (two tailed)

**Correlation is significant at the 0.01 level (two tailed)

Percent change from control condition

Several paired-sample t tests were conducted (with Bonferroni corrections) to compare percent changes between the verb and noun conditions for each dependent variable. We found no difference ($p > 0.80$) between the percent change of pronounced verbs ($M = 67.89\%$; SD 19.67) and nouns ($M = 68.90\%$; SD 19.10). Additionally, percent change for construction time was not different ($p = 0.26$) during verb production ($M = 128.42\%$; SD 18.64) or noun production ($M = 133.72\%$; SD 22.97). Notably, there was a significant difference in percent change from baseline for grasping errors [$t(37) = 3.00$, $p = 0.01$]; errors during noun production signifi cantly increased during noun-construct ($M = 174.78\%$; SD 151.98) compared to errors made during verb-construct ($M = 108.04\%$; SD 82.28).

Discussion

The results partially supported our hypotheses. We hypothesized first, that performance in both the motor and speech tasks would be worse in the dual-task conditions when compared to the control condition. In the case of verb generation, construction time increased, number of words generated decreased, but unexpectedly the total number of grasping errors was not different in the verb-construct condition versus the control. For noun-generation, participants' performance decreased in all three variables. In this case, the null result for verb-construct errors is notable, because it was not what was expected. Numerous studies have shown that when two tasks are completed simultaneously, the behavioural outcomes of one or both tasks is compromised (Albinet et al. 2006; Gunduz Can et al. 2017; Weigelt et al. 2009). This "dual-task interference" was hypothesized in our study. The fact that generating verbs (but not nouns) did not affect the number of errors during the building task is a null effect, but may be interpreted as a positive effect. This is because it was the only measure where no interference was observed in performance as a result of either dual-task condition. This result, independent of the correlational findings, suggests that the verb-construct condition does not hinder building to the same degree as the noun-construct condition. We see this lack of interference as a form of facilitation, an idea that is further supported by the correlational results.

Regardless of whether participants were generating verbs or nous, we found a positive correlation between construction times and grasping errors during dual-task conditions; the longer it took to construct a model the more mistakes participants made. This suggests that under increased cognitive demand, some participants continued to both accurately grasp and correctly assemble the models, which results in a faster time, while other participants selected the incorrect blocks and assembled the models inaccurately, increasing construction time. Though it appears that part of speech did not uniquely affect the grasping measures, this changed when we examined word generation.

We found that the number of verbs generated during the dual-task condition negatively correlated with construction time and grasping errors: participants who built more quickly and made fewer errors also produced more verbs (see Table 2). These significant correlations were not present during noun pronunciation. This difference between verb-construct and noun-construct indicates that construction ability can facilitate better verb generation, while noun generation does not relate to this type of motor performance. This is further supported by the significant regression, which shows that construction time of block models predicts performance on the verb fluency task.

This final finding could be regarded as support for the theory of embodied cognition, because it is only when producing speech that symbolizes action that there is a relationship between grasping behaviour and speech production. It should be noted that unlike recent imaging experiments (Hauk et al. 2004; Repetto et al. 2013), we did not control for the type of verb or noun produced. This was done intentionally to create a more natural experimental environment, but as a result, the participants generated random verbs and nouns, some of which may have been or were related to specific manual actions. According to studies using imaging, stimulation, and behavioural methods, there is often a distinction in neural activation or in kinematics between the characteristics of the verb word (i.e. if it denotes a concrete versus an abstract action [to catch versus to motivate; Repetto et al. 2013], and if it is body-part specific [to paint versus to kick; Hauk et al. 2004]. The results of the current study align with the Theory of Embodied Cognition in that verbs, which denote action, facilitated grasping behaviour. However, the study did not control for the number of concrete versus abstract words that participants generated. The theory of embodied cognition would suggest that concrete words would have affected the grasping behaviour more than abstract words. This conclusion cannot be drawn from the present study. It is important to note that this study included both left- and right-handed participants. In left handers, approximately 15–27 percent demonstrates atypical language lateralization (Knetcht et al. 2000). Between left- and right-handed participants, no significant differences were observed in performance through the different conditions. This suggests that regardless of language lateralization, verb pronunciation continued to interact with grasping performance. This could be further confirmed by recruiting left handers and using a dichotic listening test or imaging to determine their language lateralization, and examining performance during the different conditions.

As discussed in the introduction, verb and noun production activates dissociable areas, as known through neuroimaging and lesion studies. While there is common activation during these different parts of speech [i.e. left frontal lobe, Broca's areas, (Zhang et al. 2018)], verbs consistently demonstrate greater activation in the left frontal and fronto-parietal cortical networks compared to noun production (Parks et al. 1988; Shapiro et al. 2006, 2005). The same areas are routinely recruited for grasping and action planning (Jeannerod et al. 1995). This is relevant for the results found in our study. Given the shared neural components, it is possible that the relationship between verb production and grasping arises from reliance on similar architecture. Of course, according to our statistical analysis, an increase in cognitive demand results in some degradation in performance (increased time to complete model, fewer generated words), but ultimately, efficient processing and performance in one capacity (grasping) translates into similar success in another (verb production). A study examining preschoolers found that those with better fine motor skills also demonstrated better receptive and expressive language, specifically language which describes body–object interactions, a category that includes verbs (Suggate and Stoeger 2014, 2017). Additional evidence for facilitation (or at least no interference) between verb production and manual action, arises from adult populations with motor disorders (i.e. Parkinson's Disease) who selectively demonstrate verb-generation deficits (Bocanegra et al. 2015; Canessa et al. 2007; Ibanez et al. 2013; Salmazo-Silva et al. 2017).

Exploring the relationship between speech and manual actions is not only important in terms of expanding our understanding of the cognitive–motor interactions but also as tool for detecting/measuring and preventing/remediating these functions. Verbal fluency (ability to generate words which fit into categories) is routinely used as a measure of executive function (a blanket term which relates to self-regulation and emotional control), which is a vital component of daily life (Diamond and Lee 2011). The facilitatory relationship between verb production and grasping behaviour allows for the possibility that fine motor skill characteristics can be used as an early predictor of later language development, allowing for earlier intervention (Gonzalez et al. 2014b; Leonard et al. 2015). For example, a review demonstrated that children with specific language impairment (SLI) typically display poor motor skills comparable to those of a child with developmental coordination disorder (Hill 2001). Another review echoes these findings, where children with diagnosed language impairments performed worse on fine motor tasks (Rechetnikov and Maitra 2009). In these and other studies (Bishop 2002) examining children, it is clear that speech impairments are typically accompanied by motor impairments. If both skills show this association, alongside early identification of potential speech disability, we may be able to use motor skills as a target for early intervention regarding language.

In addition to improving speech, our results allow the possibility that fine motor skill training could be applied as a program for improving cognitive abilities, specifically executive function. In children affected from speech or motor delays (aphasic stroke, childhood apraxia of speech) evidence already exists that generalized training of speech or grasping skills can result in improved performance in the other modality (Berthier and Pulvermuller 2011; Maas et al. 2014). Our results suggest that it is possible that by focusing training on one domain, we would observe improvements in the other domain. An additional point of note is that our study was conducted with adult participants, so in addition to therapies benefitting children, it is possible that it could be utilized in an adult or senior population. Follow-up experiments are necessary to confirm the degree of relationship between fine motor skill and verb production. A strong association would provide means to improve motor skills by training in verb generation and vice versa, both ultimately improving cognitive functions central to daily life (Yan and Zhou 2009).

A result we have yet to address is the consistent difference between the number of generated verbs and nouns. Participants produced significantly more nouns than verbs during both the control and dual-task conditions. It could be argued that producing more words is a more cognitively demanding task, and thus explain the decrease in construction accuracy during noun generation. However, we did not find a significant correlation between noun generation and construction time or grasping errors. Similarly, one could contend that because participants generated fewer verbs, they were able to focus more on grasping and construction. Although this remains as a possibility, it is unlikely for two reasons. If the speculation that generating verbs is less demanding thus resulting in fewer grasping errors is correct, we can make the following prediction. For all dependent measures, there should be a significant difference in the percent change between verbs and nouns. Specifically, one would expect poorer performance in the more challenging noun task compared to the percent change for verb-construct conditions. We found no evidence of this. According to the statistical results, construction time increased to the same extent for both verbs and nouns during the dual-task conditions. Crucially, the percent decrease in the number of words produced during dual-task condition was identical for both nouns and verbs. This indicates that executing two simultaneous tasks results in identical ratios of performance change when generating verbs and when generating nouns. This new result, along with the finding that construction times are similarly affected during the verb- and noun-construct tasks strongly suggest that the lack of interference in grasping errors is not due to the verb-generation task being easier than the noun-generation task. In other words, despite producing fewer verbs, both tasks were equally demanding, and the differences found for grasping errors cannot be attributed to the participants completing an "easier" task. The most notable outcome from our additional analyses is a significant difference in ratio between the number of grasping errors made during the noun-construct condition compared to verb-construct. This finding highlights the lack of interference between verb production and grasping—only 8% more grasping errors were performed while generating verbs—compared to 75% more errors while generating nouns, despite the fact that there was an identical decrease in the proportion of words produced. Again, we believe that this is more than sufficient evidence that verb generation does not interfere with grasping leading us to suggest that verbs uniquely interact with, and furthermore facilitate manual action.

A second point for consideration is that the difference in noun and verb generation is consistent with previous studies, where participants produced more nouns than verbs across both control and dual-task conditions (McDowd et al. 2011; Östberg et al. 2005). Researchers argue that increased noun-generation ability is the result of the construction of each grammatical category. Nouns are naturally divided into sub-categories (i.e. there are many types of vehicles), meaning that noun generation, particularly category generation, is a skill that we naturally develop as we learn a language. In contrast, verbs are usually associated with a subject/noun, and rarely grouped, making the generation of verbs appear more unnatural compared to nouns. Because verbs also play a role in determining the tense and plurality of a statement, we have multiple ways to modify verbs (addition of morphemes, such as "il-", "-ed", "-ing"), which may result in slower selection process (Silveri et al. 2018; Vigliocco et al. 2011). These characteristics suggest that if we argued that one grammatical word class was more cognitively demanding to spontaneously generate, it would be in fact verbs and not nouns. Given this information, the explanation that producing fewer verbs resulted in fewer grasping errors is implausible.

Something that should be considered in studies involving noun and verb production is the distinction between abstract and concrete words. A recent review laid out two key issues with the current literature. First, there is a lack of consensus on a definition of concrete and abstract verbs/nouns (Mkrtychian et al. 2019). Second, there are different methodologies (stimuli and measures) used to study processing/production of concrete and abstract words (Mkrtychian et al. 2019). Despite these differences, the review (and other studies) still found significant behavioural and functional differences between concrete and abstract words (Mkrtychian et al. 2019; Moseley and Pulvermuller 2014). To encourage the production of concrete words, in the present study, we selected concrete word categories (i.e. kitchen, fruits.) and gave examples that promoted generation of concrete verbs and nouns (i.e. "baking" and "apple"). Future studies could specifically ask participants to only use concrete (or abstract) words.

Finally, it is important to note that there was a decrease in word production for both nouns and verbs, and an increase in construction time during both dual-task situations. Both speech and manual tasks experienced degradation in aspects of performance. However, increased construction errors occurred only when producing nouns. This supports our interpretation that verbs distinctly facilitate grasping behaviour despite both dual-task noun and verb conditions resulting in similar decreases in performance (increased construction time and decreased word production). In future studies, we could quantify this by setting tighter parameters on both verb and noun categories. The parameters for verbs would be identical to those used in the study, where participants used the continuous form of verbs by attaching "-ing" to the end. For nouns, we would select categories that resulted in fewer words generated (such as electronics, see Table 1), and categories which made it difficult to cluster, or name nouns in a sub-category (i.e. for animals, they could say "cats," but not name types of cats; "maine coon" and "lion", etc.). We would expect diminished differences between the number of nouns and verbs generated, but continue to observe correlations only between verb-generation abilities and motor skills.

In conclusion, this study furthers our understanding of the relationship between motor and language functions, demonstrating that when performing more natural, but cognitively demanding tasks, verb production facilitates grasping behaviour relative to noun production. This is in stark contrast to noun production, where there was no relationship between production and grasping. We propose that by improving verb-generation abilities through training, it may be possible to facilitate motor performance and vice versa. This could prove a feasible alternative for children with delays, seniors experiencing natural decline, or adults recovering from brain injury.

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