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Bidirectional Interference Between Speech and Mathematical, Language, or Visuospatial Tasks in Younger and Older Adults

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ABSTRACT

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or Visuospatial Tasks in Younger and Older Adults

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This study examined interference between three non-speech tasks and concurrent speech performance. The non-speech activity consisted of computer-based mathematical, language, and visuospatial tasks. The speech tasks included a procedural discourse monologue and a conversation. Participants included 60 adults in two age groups with 30 participants each. The younger adults were aged from 18 to 30 years and older adults from 55 to 82 years. Each participant completed the non-speech tasks in isolation, the speech tasks in isolation, and then each of the speech tasks concurrently with each of the three non-speech tasks. Speech acoustic measures included the mean and standard deviation of intensity and fundamental frequency as indicators of prosody, speaking time ratio to reflect speaking versus pausing time, and speech rate. Non-speech measures included total responses, correct responses, and accuracy. Statistical analysis revealed significant divided attention effects on speech, with increases in fundamental frequency and decreases in speaking time ratio, speech rate, and intensity. Performance on all non-speech tasks was negatively impacted by speech, as there was a significant decrease in total responses and total correct responses overall. There was a significant age effect for intensity and fundamental frequency variability, in that the younger group had less prosodic variation compared to the older group. The present findings provide some evidence that the effects of divided attention increase with age, as older adults gave fewer responses than younger adults overall. However, results indicate older adults prioritize accuracy over speed compared to younger adults. These findings suggest that bidirectional interference occurs between speech and mathematical, language, and visuospatial tasks. The results expand what is known about bidirectional interference between speech and other concurrent tasks, as well as the effects of age on divided attention.

Keywords: divided attention, bidirectional interference, age, discourse, speech acoustics

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DESCRIPTION OF THESIS STRUCTURE AND CONTENT

This thesis, *Bidirectional Interference Between Speech and Mathematical, Language, or Visuospatial Tasks in Younger and Older Adults* is written in a hybrid format. A hybrid format allows the requirements of a traditional thesis and journal publication formats required for the field of Communication Disorders to be brought together, and the preliminary pages of the thesis reflect the requirements for submission to Brigham Young University. The literature review is included in Appendix A, Appendix B includes the consent/institutional review board approval letter, a list of procedural discourse prompts used in the study are included in Appendix C, and a list of conversation prompts used in the study are included in Appendix D.

Introduction

Divided attention is needed to perform multiple tasks at once. It is common for individuals to divide their attention across multiple activities, and it is becoming more prevalent with the proliferation of interactive devices. However, there are times when multi-tasking is efficient and times when it is not. While an individual can complete one attention-demanding task while simultaneously completing a second task, it commonly results in a loss of efficiency on the first task. This decline in performance when attention is divided is referred to as interference (Bailey & Dromey, 2015). A common example of this is an individual who speaks while completing a concurrent task. Previous literature has shown that speech production can be affected by the concurrent performance of other tasks, even in people without speech disorders (Dromey & Bates, 2005; Dromey & Benson, 2003; Dromey & Shim, 2008). However, divided attention has not always been examined in the context of the ecological validity of speech tasks. Because of this, we seek to understand the interference between concurrent speech and nonspeech tasks under naturalistic speaking conditions.

Cognitive psychologists have developed models of attention through many research studies over the last few decades. These models, or theories of attention, provide insight into how individuals complete two tasks at the same time and explain why interference occurs in dual-task situations. Two theories are prevalent in the field of divided attention: structural theories and capacity theories (Wickens, 1981). Structural theories present the idea that there is a limit to cognitive processing due to differences in task structure. Due to this difference, only one item can be processed at a time. Thus, a single serial "bottleneck" occurs during dual-task conditions, and attention is occupied with the first task before being directed to the second. This causes interference with the other task (Navon & Miller, 2002; Wickens, 1981). However, some researchers present the argument that such a specific model cannot account for the complexities and multi-faceted relationship between all types of dual tasks. The bottleneck theory is too limiting to describe dual-task interference (Navon & Miller, 2002). Therefore, a capacity theory could present a more thorough explanation for attention processing. Capacity theories propose that the brain has a limited capacity. When concurrently performing two tasks at once, attentional resources become limited, as one task becomes more difficult and demands more attentional resources, performance in the secondary task declines (Norman & Bobrow, 1975; Wickens, 1981). Working within the capacity theory, Norman and Bobrow (1975) suggest that our attention is a finite resource that provides a pool of possible resources when completing a task. When presented with multiple processes competing for resources, the brain allocates some resources to each task. This theory suggests interference occurs when the available resources are insufficient for both tasks (Norman & Bobrow, 1975).

The theories described above are possible explanations for why interference occurs when completing two tasks at the same time. However, Navon and Gopher (1979), proposed a theory that considers multiple attentional resource pools instead of the idea of a single, central pool. A multiple resources model proposes that dual tasks that require similar resources are going to cause more interference than those that use different types of resources (Navon & Gopher, 1979). This provides some insight into why a specific task type or modality will lead to more interference than others in dual-task conditions. For example, the performance of two linguistic tasks would result in greater interference than linguistic and visual task performance. A further theoretical framework for the multiple attention model details the addition of four distinct dimensions. These four dimensions include stages of processing, codes of processing, perceptual modalities, and visual channels. These four dimensions add understanding to how performance breakdowns are related to dual-task overload, by comparing the extent to which two concurrent tasks share common demand for each of the four dimensions (Wickens, 2008).

Similar to the multiple resources model is the functional distance hypothesis. This theory centers on the localization of functions within the brain and suggests that the interference caused by the performance of two tasks is due to the physical distances between the brain structures processing the tasks. The degree of interference between two tasks is directly related to the distance of cerebral control centers (Kinsbourne & Hicks, 1978). This model concludes that tasks with increased similarity will involve more interference because they work within the same areas of the brain. An example of this would be performing two tasks that require language at the same time, such as talking while writing a to-do list. McDowd and Craik (1988) added further understanding of this theory by proposing that younger brains may more easily keep two tasks functionally distinct while performing them concurrently. Older brains could have more difficulty separating the functionality of tasks due to the atrophy that occurs in the aging brain. This atrophy may decrease the ability to maintain distinct resource pools, and as resource pools become less separate, this decreases the functional distance between them. According to the functional distance hypothesis, the lessened distance between resource pools would cause increased interference when performing tasks.

This is one example of many cognitive changes that arise from aging that have encouraged researchers to study divided attention across the adult lifespan. A meta-analysis of 33 dual-task studies (Verhaeghen et al., 2003) showed that there is a significant age-related deficit in dual-task performance, even after controlling for single-task performance, task complexity, and expected general slowing that is present with the aging brain. Though the study was measuring effects for both reaction time and accuracy, the only effect found on performance was reaction time. Though it is reasonable to assume that adding a secondary task when completing a single task would result in less accuracy, this study concluded that no aging effects were associated with accuracy. This demonstrates that older adults may simply prioritize accuracy over speed, and when performing concurrent tasks, have a delayed reaction time compared to younger adults. It seems that younger and older adults adopt different strategies to manage the negative effects on performance that occur while completing tasks that require divided attention. Göthe et al. (2007) suggested that older adults assume a more conservative approach to the demands of dual-task performance where they trade speed for better accuracy, whereas younger adults opt for a riskier approach that prioritizes speed over accuracy.

These alternate strategies are used to manage the costs associated when dividing attention between two tasks. Additionally, research has shown that young and older adults adopt different strategies to deal with the costs of speech production as well. Speaking while completing a task requires the demands of planning, producing, and monitoring speech (Kemper et al., 2011). These demands result in negative effects on young and older adults' dual-task performance when completing complex language and visual motor tasks at the same time (Dromey & Bates, 2005; Kemper et al., 2009; Kemper et al., 2011). Kemper et al. (2009) conducted a study to determine if language use was affected while individuals simultaneously completed a language production task and a visuospatial tracking task. Their results revealed that younger adults were more affected than older adults when it came to language effects. Younger adults experienced a decline in propositional content, grammatical complexity, and sentence length, whereas older adults only experienced a decrease in speech rate. When investigating the reason why this occurred, the researchers found that the young adults in their study used faster, more complex speech initially. The researchers concluded that the younger adults' use of complex speech at baseline made them more vulnerable to dual-task demands when resources became limited. This caused them to use shorter and simpler sentences.

Researchers also found that this difference in language effects is due to a strategy older adults adopt. It seems that older adults use a more restricted speech style comprised of short, simple sentences with few fillers as a strategy to compensate for working memory and processing speed. Limitations in working memory affect older adults' ability to plan and produce complex, multi-clause utterances. Limitations in processing speed affect sentence planning and production aspects, such as ideation and word retrieval. Fortunately, the use of a restricted speech style helps older adults compensate for these age-related declines (Kemper et al., 2009; Kemper et al., 2011), which allows them to complete other concurrent tasks, such as walking or watching television. However, it is important to note that older adults can still experience increased costs of performance if they deviate from this restricted style of speech and produce utterances that are more informative, propositionally dense, or grammatically complex (Kemper et al., 2011).

Aside from speech, further research has been done to examine the relationship between divided attention and other performance effects. Findings suggest a decline in performance in a variety of tasks, such as postural stability (Dromey et al., 2010), manual tasks (Dromey & Bates, 2005), driving (Dromey & Simmons, 2019; Glenn, 2017), and memory (Naveh-Benjamin et al., 2003). Additionally, previous work has demonstrated effects on speech-motor performance during a variety of dual-task conditions, including linguistic, cognitive, and manual motor tasks. For example, Bailey and Dromey (2015) performed a study of interference between three different types of tasks and speech. Their results showed that both speech and the other concurrent tasks had effects on the other, as well as age effects on speech motor control.

Additionally, the study determined that task type plays a significant role in the stability of speech movement patterning when attention is divided. This provided further evidence in support of previous findings that when speech and non-speech tasks are performed concurrently, interference causes a decline in performance. However, the study was performed with a speech task involving controlled stimuli – saying the same sentence repeatedly. This design allowed the researchers to compare detailed speech movement metrics across different non-speech tasks during data analysis. However, it resulted in the study having overall reduced ecological validity, as it did not represent functional everyday speech.

The study conducted by Bailey and Dromey (2015) was one of many experiments studying concurrent speech tasks that used a repetitive speech stimulus. This methodological decision allows for increased experimental control, the ability for researchers to measure a consistent speech target, and more straightforward statistical comparisons. While these are important factors to consider when investigating speech variables, it is also important to consider the ecological validity of such tasks. In everyday conversations, it is common for conversation partners to overlap or interrupt each other when speaking, as they share control of topics, and there is no rigid turn-taking in everyday conversation (Simmons-Mackie et al., 2007). The use of a repetitive speech stimulus is not reflective of the natural fluctuations that occur in more common speaking environments. In this study, we will address this problem by using more naturalistic speaking conditions, since rote speech tasks would not validly reflect the type of communication a person would use in everyday life.

One suitable option for a more ecologically valid speech condition would be discourse. Discourse is described as any unit of language that is longer than a sentence and used for a specific purpose or function (Dipper & Prichard, 2017). Monologues are a form of discourse that differs from conversation. A monologue allows an individual to use typical linguistic elements in communication that closely resemble but are more structured than those used in everyday conversation. The goal would be to measure spoken language production in a way that can generalize to a person's everyday life (Simmons-Mackie et al., 2007). There are various kinds of discourse available to use in daily speech. Some examples include narrative discourse (explaining an event), procedural discourse (providing directions or instructions), descriptive discourse (describing something in detail), and expository discourse (explaining something in depth; Boyle, 2011). Discourse is considered a more ecologically valid task than sentence repetition because each kind of discourse is frequently used in everyday communication; speakers typically switch between discourse types and vary the syntactic structures when communicating throughout the day. Additionally, it can be used as a structured speech task by narrowing the discourse to one type, allocating turns between speakers, or controlling the topic (Boyle, 2011). For these reasons, a procedural discourse speaking task was selected for the current study. This type of task was selected to provide a condition with some topic constraints. This structure allows for the comparison of data across conditions and provides ample speech output from each participant to ensure a measurable sample. Along with a procedural discourse task, a loosely scripted conversation was also used as a secondary speech task to allow the greatest ecological validity.

As discussed previously, individuals experience interference when performing a task and speaking simultaneously. Some measures of interference only reflect how a task would affect speech, without quantifying performance on that task. For example, measuring the impact of background noise on speech only shows how interference affects speech. However, some research designs reveal how interference can be bidirectional. This means that measures can show the quantifiable impact of speaking while multitasking on the non-speech task as well. For example, Dromey and Bates (2005) conducted a bidirectional study that has shown how speaking while completing a linguistic-based task not only causes interference in speech but also causes interference in the linguistic task. A later study showed that speaking while completing a cognitive task and a linguistic task also negatively impacted the cognitive task, linguistic task, and speech (Bailey & Dromey, 2015). Additionally, a study by Glenn (2017) revealed that speaking while driving has also been shown to cause bidirectional interference. Many tasks are commonly performed while speaking, such as checking emails, cooking dinner, walking to the store, checking an update on social media, or watching television. Therefore, understanding the impact of speech on other tasks is also important.

The purpose of the current study is to examine the bidirectional interference between speech and non-speech tasks. This will be completed by examining the effect of different modalities of tasks under more ecologically valid speaking conditions. Specifically, we will study concurrent tasks designed to address different cognitive abilities as they are performed concurrently with a more naturalistic speaking task. The study will also examine the effects of dual-task performance on older adults compared to younger adults. Observing bidirectional interference on speech and non-speech task performance will provide further knowledge about how speech shares attentional resources, and whether this sharing changes with aging. It is hypothesized that performance during concurrent tasks will decline relative to the isolated task conditions. Additionally, it is hypothesized that older adults may experience a greater decline than younger adults in concurrent task performance due to the cognitive and other changes associated with aging.

Method

Participants

This study included 60 participants in total. There were 30 younger adults (15 men and 15 women) from the age of 18 to 30 years and 30 older adults (15 men and 15 women) from the age of 55 to 82 years. They were all recruited from the local community around Brigham Young University. The participants reported no history of speech, language, or hearing disorders, except for one younger male participant who reported having a mild stutter. They were all native speakers of Standard American English. All younger adult subjects passed a hearing screening at 30 dB HL and all older adult subjects passed the screening at 40 dB HL, except one male participant. Each participant signed an informed consent document that had been approved by the Brigham Young University Institutional Review Board.

Instrumentation

The participants were fitted with a head-mounted microphone (AKG C420) to record their speech while seated in a sound booth. This signal was digitized with a FocusRite Scarlett 2i2 USB analog to digital converter at 44,1000 Hz and Adobe Audition software (Adobe Audition Team, 2019). The microphone was positioned approximately 5 cm from the participant’s mouth.

All non-speech tasks were performed on an Apple laptop. The participants were told to use either the provided mouse or the laptop’s trackpad, whichever they felt more comfortable using throughout the study. The primary and secondary non-speech tasks involved custom Matlab applications (Mathworks, 2021).

Procedures

All participants completed two types of speaking tasks – a procedural discourse monologue and a loosely scripted conversation involving common questions about the participants' daily life. These tasks were selected to allow for the greatest ecological validity, permitting improved generalization of the findings of this study to everyday situations.

Participants were required to speak for sixty seconds on a procedural discourse prompt and to engage in sixty seconds of speech during a conversation with the researcher. The procedural discourse task entailed explaining the steps or process necessary to accomplish a task. An example of this task would be responding to the prompt: “Explain the process of finding and purchasing groceries at a grocery store.” A complete list of the procedural discourse prompts used in the study can be found in Appendix C. At the beginning of the study, each participant was provided a list of 20 prompts to browse and then instructed to choose and circle eight they felt comfortable explaining for sixty seconds. The second speech task consisted of a sixty-second conversation with the same researcher for every recording. All participants were asked four of the same six conversational questions. These were chosen according to the age and life experiences of the participant. Each prompt consisted of a common topic in conversation, such as: “Where are you from?” or “Tell me about your family”. Certain questions required modification depending on the participant's life history, but all questions remained relevant to that individual. Participants conversed with the researcher for a full sixty second conversation, which usually required follow-up questions about the chosen topic to continue the conversation for the duration. All participants were allowed to ask questions to the researcher during the task, though few took advantage of this invitation.

The non-speech tasks addressed three different cognitive abilities. The mathematical task involved deciding whether a mathematical equation was correct. On the computer screen, the participant used a mouse to select “yes” if the equation was correct (e.g., 12 x 2 = 24) or select “no” if the equation was incorrect (e.g., 90 – 1 = 80). The participant was given sixty seconds to evaluate as many quantity comparisons as possible. During the divided-attention condition, participants completed the cognitive task while they explained a procedural narrative or conversed with the researcher, as described above. Different mathematical equations were given for each condition.

The language task involved deciding whether two words (a noun and a verb) were semantically related. For example, the participant would view the words “mouth” and “eating” on the computer screen, and they would select “yes” because they make a semantic pair. If the pair did not match (e.g., “dough” and “interviewing”) the participant would select no. The participants were given 60 seconds to complete the task. During the divided-attention condition, participants completed the linguistic task while they produced a procedural narrative or conversed with the researcher, as described above. Different word pairings were given for each condition.

The visuospatial task involved determining whether two figures were the same or not. The computer screen displayed two images with shapes merged to make a figure (see Figure 1). One of the figures was rotated into a different orientation. The participant used a mouse to select “yes” if the figures were determined to be identical. The participants were given sixty seconds to complete the task. During the divided-attention condition, participants completed the visuospatial task while they produced a procedural narrative or conversed with the researcher, as described above. Different figures were given for each condition.

Each participant engaged in a speech-only task, a non-speech task, and a concurrent speech and non-speech task. For the dual-task conditions, the participants were instructed to speak continuously for the entirety of the task. Before completing each type of task for the first time, instructions were given, and the participants were given a brief amount of time to practice and become comfortable completing the task.

Data Analysis

Acoustic Measures

Praat speech analysis software (Version 6.2.14; Boersma & Weenink, 2022) and custom Matlab applications (Version 2023a; Mathworks, 2021) were used to obtain acoustic measures from the audio recordings that would quantify prosody, speaking rate, and speaking versus pausing time. Due to the nature of the speaking tasks, the measures chosen were more appropriate for interpreting paragraph-level speech as opposed to segmental-level acoustic metrics. The same speech measures were used in both the isolated speech task and the combined tasks. This allowed for a comparison of participant performance between conditions. Before the recordings were analyzed, non-speech sounds such as researcher speech, coughing, or laughing were deleted from the audio. After these were removed, the first sixty seconds of each speech task were used in the analysis.

Acoustic speech measures included the mean and standard deviation of intensity and fundamental frequency as indicators of prosody, speaking time ratio to reveal pausing effects and speech rate in words per minute. The softest speech sound in each recording was chosen as a dB floor to remove the influence of non-speech sounds or pauses on the intensity measures. The intensity record from Praat was exported as a comma-separated values file (CSV) which was analyzed with a custom Matlab application. This application computed both the mean and standard deviation of the intensity during each recording for all values above the dB floor. Speaking time ratio, a measure of time speaking versus pausing was computed in a Matlab application and expressed as a proportion. 1.0 would indicate the sample included no pause time, with the participant speaking the whole time. 75% speech and 25% pause would be indicated with a .75 and so on. Speech rate was measured in words per minute, which involved counting the number of words produced between 10 and 40 seconds in each 60-second speech sample and then multiplying it by 2.

Non-Speech Measures

The non-speech task analysis consisted of tallying the total responses from each participant and the total correct responses for each task. This allowed a computation of the percent correct on the non-speech task performance.

Statistical Analysis

A linear mixed model (LMM) analysis using SPSS 28 software tested the changes in the dependent measures (acoustic measures, computer measures) across the dual-task and single-task conditions. Task condition and age group were fixed effects, while individual speakers were a random effect in the model. Speaker sex was included as a covariate.

Results

The descriptive statistics for the speech acoustic measures for discourse and conversation are reported in Tables 1 and 2. Descriptive statistics for the non-speech tasks are reported in Table 3. The main effects and multiple comparison results for the discourse, conversation, and non-speech tasks measures are reported in Tables 4, 5 and 6.

Effects of Non-Speech Tasks on Speech

There was a significant main effect for fundamental frequency. The comparison analysis revealed that fundamental frequency increased during the concurrent visuospatial and discourse task compared to the discourse only condition. Additionally, there was a significant main effect for speaking time ratio. Comparison analysis revealed that during the combined discourse and non-speech conditions, the speaking time ratio decreased for each of the concurrent non-speech tasks, as shown in Figure 2. There was a significant main effect for intensity mean and standard deviation. Comparison analysis revealed that the mathematical task and visuospatial task led to a decrease in the mean intensity compared to the discourse only condition. Analysis also revealed that intensity standard deviation significantly decreased during the concurrent discourse and language non-speech task. Lastly, a significant main effect of condition on speech rate was revealed. Comparisons revealed speech rate decreased during discourse with all three non-speech task conditions, as well as conversation with the mathematical and language task. These results are reflected in Figures 3 and 4.

Effects of Speaking on Non-Speech Task Performance

A significant main effect was found for the number of total responses and the number of correct responses for all three non-speech tasks. Comparison analysis revealed that the number of total responses and the number of correct responses significantly decreased for both the conversation and discourse conditions while concurrently performing the language, mathematical, and visuospatial tasks.

The LMM testing also revealed a significant main effect for the percent of correct responses on the mathematical and visuospatial tasks. The comparisons revealed that there was a significant decrease in the percentage of correct responses when participants completed the mathematical task while concurrently performing the discourse task. Additionally, there was a significant decrease in the percentage of correct responses during the visuospatial task while concurrently performing the discourse and conversation tasks.

Age Effects on Speech and Non-Speech Task Performance

There was a significant effect of age on multiple speech variables, including fundamental frequency, intensity mean and standard deviation, semi-tone standard deviation, and speech rate. Comparisons revealed that younger speakers had higher fundamental frequency, mean intensity, and a higher speech rate compared to the older speakers across all conditions. Comparison analysis also revealed that the older speakers had higher intensity variability than the younger speakers when completing non-speech tasks concurrently with discourse and conversation. Additionally, the older speakers had higher semitone standard deviation, meaning they had higher fundamental frequency variability, than the younger group during the discourse task (see Figure 5).

There were significant age effects for the number of total and correct responses in all three non-speech tasks. Older speakers had lower performance for each of the non-speech task variables, including total responses and total correct responses. Though significant age effects were found for overall responses, the percentage of correct responses did not significantly decrease, indicating that older adults were just as accurate as the younger participants when completing non-speech tasks. These findings are reflected in Figures 6 and 7.

Discussion

This study examined the effects of concurrent speech and non-speech tasks on each other. This study also considered the effects of age on divided attention performance, and it was hypothesized that older adults may experience a greater decline than younger adults in concurrent task performance. Statistical analysis revealed several significant effects on speech and non-speech task performance; there were also significant performance differences as a function of age. The present results are consistent with previous research, including that of Bailey and Dromey (2015) and Bateman (2022).

Effects of Concurrent Tasks on Speech Measures

The results show that participating in different types of tasks while speaking can negatively affect speech. There were changes in all speech measures, including fundamental frequency, intensity, speaking time ratio, and speech rate. The three types of non-speech tasks – mathematical, language, and visuospatial – affected speech differently.

The speaking time ratio and speech rate decreased for all task types during discourse. These results are consistent with previous studies showing that divided attention impacts speech performance when completing language, visuomotor, and cognitive tasks (Bailey & Dromey, 2015; Dromey & Bates, 2005; Dromey & Shim, 2008). One study by Kemper et al. (2011) found that motor-tracking tasks led to more pause time in speech, both before and after utterances, during concurrent task performance. Further, Bateman (2022) found that when completing a data entry task, both speech rate and pausing were affected negatively. Both studies showed a decrease in overall speaking time during the concurrent tasks, which aligns with the results of the current study.

In the divided attention conditions both the speech and non-speech tasks would have required attentional resources, which led to interference. Therefore, it could be suggested that the reason for decreased speech rate and speaking time is that the participants required more processing time. Due to the increase in attentional demand, it likely required more cognitive effort for the participant to plan and produce speech while completing the non-speech task, leading to the need to slow down and insert more pauses.

While speaking time and speech rate were affected by all three types of tasks during the discourse condition, speech rate only decreased during the mathematical and language task in the conversation condition. Because of this, it could be suggested that the mathematical and language task interfered more than the visuospatial task when participating in conversation. This finding appears to follow the functional distance hypothesis (Kinsbourne & Hicks, 1978), which predicts that two tasks will have more interference when the brain structures processing them are closer together anatomically. On the basis of this theory, it could be suggested that language formulation in conversation uses neural centers closer to semantic and quantitative reasoning than visual processing. Conversely, another possible explanation could be difference in the way individuals reason through different types of tasks. While completing the mathematical and language task, it is likely participants used verbal mediation as a part of their reasoning process. However, it is less likely that participants would use the same mental strategy when completing the visuospatial task. This could be a potential reason why the mathematical and language task interfered more than the visuospatial task when participating in conversation.

Divided attention conditions also resulted in a decrease in the intensity of speech compared to the speech-only condition. Mean intensity decreased during the visuospatial and mathematical task with discourse, while the standard deviation of intensity decreased during the language task with discourse. Additionally, mean fundamental frequency increased during the visuospatial task with discourse. These findings are in contrast with previous studies. Glenn (2017) and Dromey and Simmons (2019) found that participants spoke with greater intensity while driving and speaking into a hand-held phone while participating in conversation or performing a monologue. These authors speculated that participants spoke louder because they were required to hold a phone, requiring more effort and motor control. Dromey and Bates (2005) found similar results. Their study reported that vocal intensity increased during dual-task conditions involving a manual motor and rote speaking task. However, the participants were instructed to repeat a rote phrase after a beep. It is possible that an anticipatory reaction occurred and caused increased intensity that is not indicative of natural speaking conditions.

One possible explanation for why intensity decreased is due to the level of difficulty with the tasks. As the tasks required more attention cognitively, it is possible participants became more distracted and their loudness declined as they became more hesitant. Additionally, because of the nature of the discourse speaking task, they were speaking to a microphone and not interacting with a conversational partner. Therefore, it could also be inferred that they did not prioritize loudness as one might when talking to a conversational partner.

Each type of task was performed concurrently with two different ecologically valid speaking conditions: a procedural discourse task, and a conversation with the researcher. However, the majority of significant effects were from the discourse condition. There are a few possibilities for why this occurred. The first is that the conversation allowed a break in attentional demand while the researcher asked a follow-up question or made a comment. Though short, even a small break from the attentional demand could have allowed the participant to manage the interference, allowing speech to remain relatively unaffected. Another possibility is that while the goal of the present study was to use naturalistic speaking tasks, the intermittent nature of the conversation may not have provided the opportunity to find significant changes in speech production. When participating in natural conversation, the length of utterance can vary widely due to the unpredictable pattern of exchanges between two conversational partners.

Therefore, the amount of variability that occurred in participants' phrase lengths could have made it difficult to detect trends in the acoustic measures.

Effects of Speaking on Non-Speech Task Performance

The non-speech tasks were completed both on their own and concurrently with two speaking conditions to measure the effect that speech had on them. All non-speech tasks were negatively impacted in the divided attention condition for both the procedural discourse and conversation conditions. This impact was observed through a significant decrease in both the number of overall responses for each type of task and the number of correct responses for each type of task. These findings are consistent with previous reports in the literature. Dromey and Shim (2008) found manual-motor scores significantly decreased when concurrently performing a verbal fluency task. The results are also consistent with the literature reporting that performing a concurrent speech task negatively impacted a motor-tracking computer-based task (Kemper et al., 2011). Additionally, Bailey and Dromey (2015) found that accuracy decreased during both linguistic and cognitive tasks. Bateman (2022) reported negative effects of speaking on computer tasks designed to resemble those that people perform in everyday life. These findings are in line with the effects found in the present study, suggesting that an overall decrease in speed occurs while trying to speak and complete different types of tasks.

The percentage of correct responses decreased when participants completed the mathematical task with discourse and the visuospatial task with discourse and conversation. It could be speculated that the present data included a decrease in the mathematical and visuospatial task performance but not the language task performance because of task difficulty. The non-speech task scores in the isolated condition suggest that the language task may have been easiest, with participants responding more overall when completing the non-speech task in isolation. The language task required the participants to make semantic decisions, which has a higher likelihood of being intuitive for most people in their daily lives. Conversely, mathematical or visuospatial decision-making is likely to happen less frequently in daily life, possibly making these tasks harder. Although task difficulty has been shown to affect interference from divided attention (McDowd & Craik, 1988), it was not specifically measured in the present study, and the results should be interpreted accordingly. However, task difficulty likely played a role in the results because participants reported anecdotally that the visuospatial task was the most difficult of the three.

Age Effects on Performance in Divided Attention Conditions

There was a significant age effect for all five of the speech measures. Fundamental frequency, mean intensity, and speech rate were all lower in the older speakers. Conversely, the older group had higher standard deviations for intensity and fundamental frequency overall, indicating that the younger group had less variation in prosody across the speaking conditions. Variations in intensity and fundamental frequency create intonation patterns which contribute to effective communication by conveying meaning and emotion. Therefore, reduced variability in prosody measures such as those used in the present study can result in less natural sounding speech. These findings are similar to the trends reported by Dromey and Simmons (2019), which showed that when speaking while driving, younger adults had less variation in prosody compared to two older groups. These findings suggest that this may be a speech strategy older individuals adopt to compensate for other aging effects. Research has shown that younger adults tend to use more complex language, full of intricate propositional and grammatical features and a longer sentence length, while older adults tend to use a simpler style that is shorter, slower, and less complex (Kemper et al., 2009). These findings warrant further investigation through the examination of the intonation patterns of younger and older adults in future studies.

The present findings provide some evidence that the effects of divided attention increase with age, as there were age-related differences on each of the non-speech tasks as well. Older adults responded fewer times and were less accurate during the mathematical, language, and visuospatial tasks, regardless of condition. This finding is consistent with previous literature that found age differences in dual-task costs (Bailey & Dromey, 2015; Dromey et al., 2010; Kemper et al., 2011; Verhaeghen et al., 2003). However, although the older adults' total responses and total correct responses decreased, the percentage of correct responses overall did not significantly decrease. This means that the older adults were just as accurate as the younger participants when completing non-speech tasks, suggesting that the older adults prioritized accuracy over speed. This conclusion is in line with what Verhaeghen et al. (2003) found, as they concluded that there were no aging effects associated with accuracy and demonstrated that older adults may prioritize accuracy over speed. The finding that older adults trade lower speed for accuracy has also been suggested by Göthe et al. (2007). They examined whether older adults could acquire the skills of performing two cognitive tasks concurrently, using sequential, alternating, and simultaneous cognitive task conditions. They wanted to learn whether older adults could shift from a serial to a parallel processing technique through practice of performing two cognitive tasks concurrently. They found that none of the adults could acquire parallel processing skills. This supported the idea that there are significant age differences in dual-task costs and demonstrated that age-related deficits in divided attention persist even after practice. This suggests that older adults executive function strategies may be more conservative than younger adults. This interpretation is supported by additional research (Kemper et al., 2011) which showed that older adults may adopt certain strategies to compensate for age-related declines in working memory and processing speed. Therefore, the present study accords with previous literature suggesting that there is a difference between how younger and older adults approach dual-task situations.

Limitations of the Present Study and Directions for Future Research

The current study was limited by several factors that could be addressed in future research. One limitation was the nature of the speech tasks. Because the goal was to maximize the ecological validity by having participants produce spontaneous spoken language, the speech acoustic variables were limited to measures of prosody, speaking time compared to pausing time, and speech rate. It is possible that these measures may not have been sensitive enough to detect small changes in speech that would have been measurable through finer-grained segmental analysis. It is likely that using more detailed measures such as kinematics or articulatory acoustic analysis would allow for additional significant findings. A further limitation could be the nature of the conversation task. The naturally occurring turn-taking led to variation in the length of time participants spoke. This resulted in conversation speaking tasks having less than 60 seconds of participant speaking time, compared to the discourse monologue task that ensured participants spoke for a full 60 seconds. This may have caused less analyzable speech in the conversation overall than in the monologue condition because of the nature of the conversation.

The same topics were not used for all participants in the discourse tasks. Although the participants selected beforehand which topics they would prefer, this resulted in the prompts varying in content from one participant to the next. Some may have been easier to discuss, while others might have been more stressful. Future studies could investigate the potential effect of emotion on concurrent task performance, and whether speaking about emotional or stressful topics influences measures of speech or non-speech task performance. Additionally, future research could evaluate the comfort of the conversational partner when conversing with participants. This could provide insight into the effects of divided attention on the successful exchange between partners when concurrently multitasking and speaking to others. This could also include a consideration of eye contact and the effects this has on ease of conversation.

While the present study employed language and mathematical tasks similar to those used by Bailey and Dromey (2015), future studies could examine other cognitive demands, because the tasks chosen for the present study included only limited attentional requirements. Future work could use functional neuroimaging to explore the cortical activity that occurs with different types of tasks.

Another limitation was that task difficulty was not specifically manipulated or controlled for in the present study. While it is likely task difficulty plays a significant role in divided attention task performance, the current study did not systematically measure these effects. Future studies could include task difficulty as an independent variable. It would also be valuable to interview participants at the end of the experiment and ask them to describe which task was more difficult.

Finally, the present study examined healthy adults in two different age groups. Future studies could extend these findings by examining other speaker groups, such as pediatric or disordered populations.

Conclusions

This study demonstrated bidirectional interference between a procedural discourse task and three non-speaking tasks and confirms the findings of several previous divided attention studies. The findings also provide insight into the effect of age on concurrent task performance.

Older individuals used wider intonation patterns than younger adults and appeared to prioritize accuracy over speed when completing divided attention tasks.

People with both typical and disordered speech regularly participate in activities that require divided attention. This can include conversing while completing a variety of tasks that use language, mathematical and visuospatial skills in everyday life. The present findings may pave the way for future clinical research that will ultimately allow speech-language pathologists to set goals and create functional therapy activities for clients with communication disorders that are more closely aligned with what they will be experiencing in their everyday lives.

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Tables

Table 1

Descriptive Statistics for Discourse Speech Acoustic Measures

	Younger Speakers							
	Dis Only		Dis with Math		Dis with Visual		Dis with Lang	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
mean F_0	169.9	47.9	171.6	51.4	171.6	50.6	172.4	50.1
STSD	2.66	0.49	2.65	0.35	2.66	0.52	2.81	0.60
dB mean	66.9	5.5	66.0	5.3	65.6	5.1	66.2	5.4
dB SD	5.73	0.68	5.59	0.83	5.59	0.70	5.52	0.85
STR	0.781	0.080	0.740	0.069	0.748	0.081	0.766	0.076
Speech rate	176.0	37.3	150.5	33.2	154.5	31.8	159.7	28.9

	Older Speakers							
	Dis Only		Dis with Math		Dis with Visual		Dis with Lang	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
mean F_0	154.0	41.5	155.4	42.2	158.5	44.6	155.7	43.2
STSD	3.03	0.83	3.14	0.78	3.07	0.77	3.15	0.75
dB mean	63.3	4.2	63.0	4.5	63.0	4.2	63.3	4.2
dB SD	7.28	1.04	6.94	1.16	7.01	1.21	6.90	0.92
STR	0.783	0.062	0.700	0.112	0.706	0.094	0.726	0.101
Speech rate	149.3	22.5	131.5	34.3	140.1	28.6	140.6	33.1

Note. Dis Only = discourse only; Dis with Math = discourse with mathematical; Dis with Visual = discourse with visuospatial; Dis with Lang = discourse with language; mean F_0 = mean fundamental frequency; STSD = semitone standard deviation; dB mean = intensity mean; dB SD = intensity standard deviation; STR = speaking time ratio; SD = standard deviation.

Table 2

Descriptive Statistics for Conversation Speech Acoustic Measures

	Younger Speakers							
	Conv Only		Conv with Math		Conv with Visual		Conv with Lang	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
mean F_0	174.3	51.9	173.0	49.6	173.6	51.2	173.1	49.0
STSD	3.04	0.71	3.09	0.79	2.95	0.63	3.00	0.70
dB mean	66.3	5.3	66.6	5.1	66.2	5.0	66.6	5.1
dB SD	6.04	0.63	5.62	0.71	5.87	0.76	5.57	0.62
STR	0.755	0.088	0.735	0.096	0.703	0.089	0.729	0.093
Speech rate	148.9	30.9	137.8	30.3	138.9	28.5	134.9	24.5

	Older Speakers							
	Conv Only		Conv with Math		Conv with Visual		Conv with Lang	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
mean F_0	156.5	43.5	157.2	42.5	158.4	42.6	158.3	41.8
STSD	3.39	0.77	3.26	0.84	3.32	0.66	3.33	0.62
dB mean	62.7	4.2	62.3	4.2	62.7	4.2	63.1	4.3
dB SD	7.16	1.00	7.60	1.09	7.27	1.13	7.24	1.39
STR	0.712	0.102	0.706	0.098	0.704	0.102	0.705	0.096
Speech rate	137.2	34.5	126.1	28.2	133.0	33.1	123.8	29.7

Note. Conv Only = conversation only; Conv with Math = conversation with mathematical; Conv with Visual = conversation with visuospatial; Conv with Lang = conversation with language; mean F_0 = mean fundamental frequency; STSD = semitone standard deviation; dB mean = intensity mean; dB SD = intensity standard deviation; STR = speaking time ratio; SD = standard deviation.

Table 3

Descriptive Statistics for Non-Speech Task Measures

	Younger Speakers						Older Speakers					
	No Speech		Conversation		Discourse		No Speech		Conversation		Discourse	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Lang TR	36.2	4.7	19.4	6.6	16.7	5.2	29.2	6.6	16.4	5.0	14.3	5.0
Lang TC	34.4	5.1	18.5	6.6	15.8	5.0	26.9	6.7	15.3	4.5	13.2	5.3
Lang PC	95.0	4.4	94.7	6.2	95.0	6.9	92.0	4.9	93.7	5.9	91.3	12.6
Math TR	22.3	5.0	19.2	5.5	12.5	4.8	19.3	5.6	13.1	5.2	10.6	3.7
Math TC	21.1	4.7	18.2	5.6	10.6	4.9	18.1	5.5	12.6	5.2	8.8	3.8
Math PC	94.7	5.0	94.8	6.7	83.3	12.4	93.4	7.8	95.9	5.0	81.8	13.1
Vis TR	15.6	3.4	14.3	3.9	11.4	3.6	12.4	2.3	11.2	3.0	9.3	2.3
Vis TC	14.3	2.7	11.7	3.7	9.1	2.9	10.9	2.4	8.9	2.9	7.0	2.3
Vis PC	92.7	6.9	81.6	12.1	80.7	11.3	87.6	12.3	79.6	13.9	75.1	14.7

Note. Lang TR = language total responses; Lang TC = language total correct; Lang PC; language percent correct; Math TR = mathematical total responses; Math TC = mathematical total correct; Math PC = mathematical percent correct; Vis TR = visuospatial total response; Vis TC = visuospatial total correct; Vis PC = visuospatial percent correct; SD = standard deviation.

Table 4

Significant LMM Main Effects and Multiple Comparison Results for Discourse Measures

	Main Effects		Age		Dis with Math	Dis with Visual	Dis with Lang
	F	*p*	*F*	*p*	*p*	*p*	*p*
mean F_0	3.793	.011	8.048	.006	.610	.007	.159
STSD	1.690	.171	7.179	.010	1.000	1.000	.236
dB mean	5.348	.002	6.028	.017	.021	.001	.521
dB SD	2.870	.038	57.013	<.001	.166	.350	.039
STR	13.129	<.001	2.695	.106	<.001	<.001	.007
Speech Rate	14.368	<.001	8.186	.006	<.001	<.001	.002

Note. Degrees of freedom for all tests were 3, 177. Dis with math = discourse with mathematical; Dis with Visual = discourse with visuospatial; Dis with Lang = discourse with language; mean F_0 = mean fundamental frequency; STSD = semitone standard deviation; dB mean = intensity mean; dB SD = intensity standard deviation; STR = speaking time ratio.

Table 5

Significant LMM Main Effects and Multiple Comparison Results for Conversation Measures

	Main Effects		Age		Conv with Math	Conv with Visual	Conv with Lang
	F	*p*	*F*	*p*	*p*	*p*	*p*
mean F_0	0.288	.834	8.351	.005	1.000	1.000	1.000
STSD	0.396	.756	3.629	.062	1.000	1.000	1.000
dB mean	1.829	.144	9.719	.003	1.000	1.000	.605
dB SD	1.390	.247	62.693	<.001	1.000	1.000	.526
STR	2.105	.101	1.428	.237	1.000	.080	1.000
Speech Rate	4.693	.004	2.681	.107	.030	.416	.003

Note. Degrees of freedom for all tests were 3, 177. Conv with math = conversation with mathematical; Conv with Visual = conversation with visuospatial; Conv with Lang = conversation with language; mean F_0 = mean fundamental frequency; STSD = semitone standard deviation; dB mean = intensity mean; dB SD = intensity standard deviation; STR = speaking time ratio.

Table 6

Significant LMM Main Effects and Multiple Comparison Results for Non-Speech Tasks Measures

	Main Effects			Age Effects		Conversation		Discourse	
	df	*F*	*p*	*F*	*P*	*df*	*p*	*df*	*p*
Lang TR	2, 117.142	374.419	<.001	11.248	.001	117.221	<.001	117.221	<.001
Lang TC	2, 117.096	322.810	<.001	13.074	.001	117.177	<.001	117.177	<.001
Lang PC	2, 117.420	0.439	.646	3.309	.074	117.551	1.000	117.551	1.000
Math TR	2, 118.000	140.933	<.001	10.754	.002	118.000	<.001	118.000	<.001
Math TC	2, 118.000	165.750	<.001	9.448	.003	118.000	<.001	118.000	<.001
Math PC	2, 118.000	49.454	<.001	0.115	.736	118.000	1.000	118.000	<.001
Vis TR	2, 116.942	63.969	<.001	13.827	<.001	116.997	.001	116.997	<.001
Vis TC	2, 116.989	94.118	<.001	18.054	<.001	117.059	<.001	117.059	<.001
Vis PC	2, 117.479	28.095	<.001	2.973	.090	117.594	<.001	117.594	<.001

Note. Lang TR = language total responses; Lang TC = language total correct; Lang PC; language percent correct; Math TR = mathematical total responses; Math TC = mathematical total correct; Math PC = mathematical percent correct; Vis TR = visuospatial total response; Vis TC = visuospatial total correct; Vis PC = visuospatial percent correct.

Figures

Figure 1

Example of a Visuospatial Task Shape Mismatch

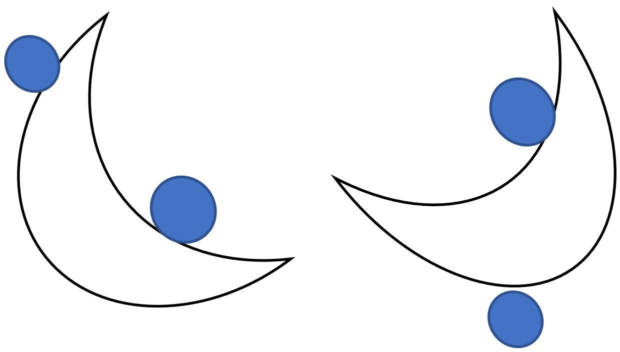
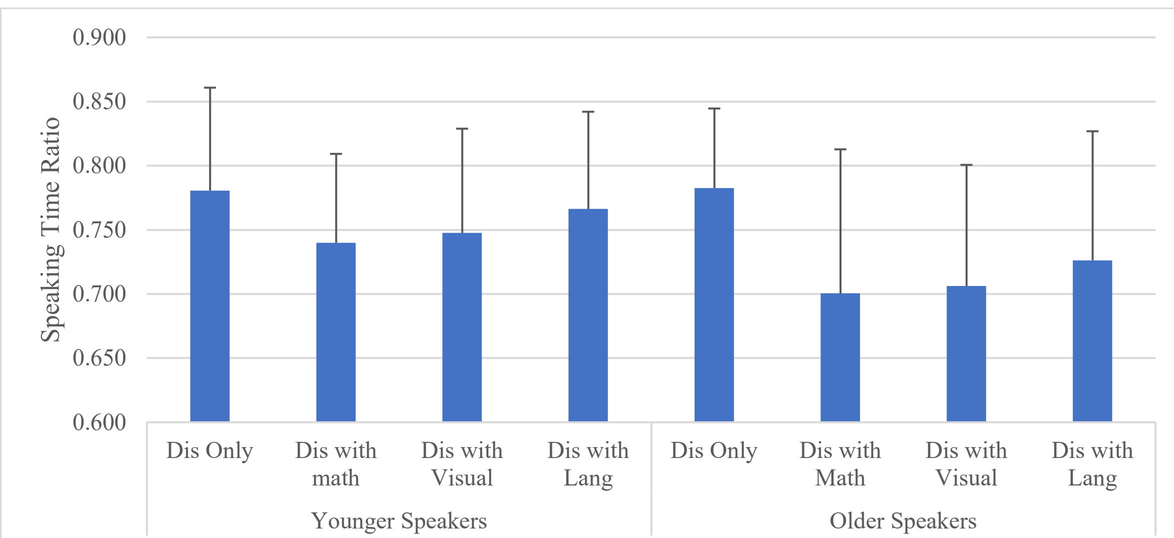


Figure 2

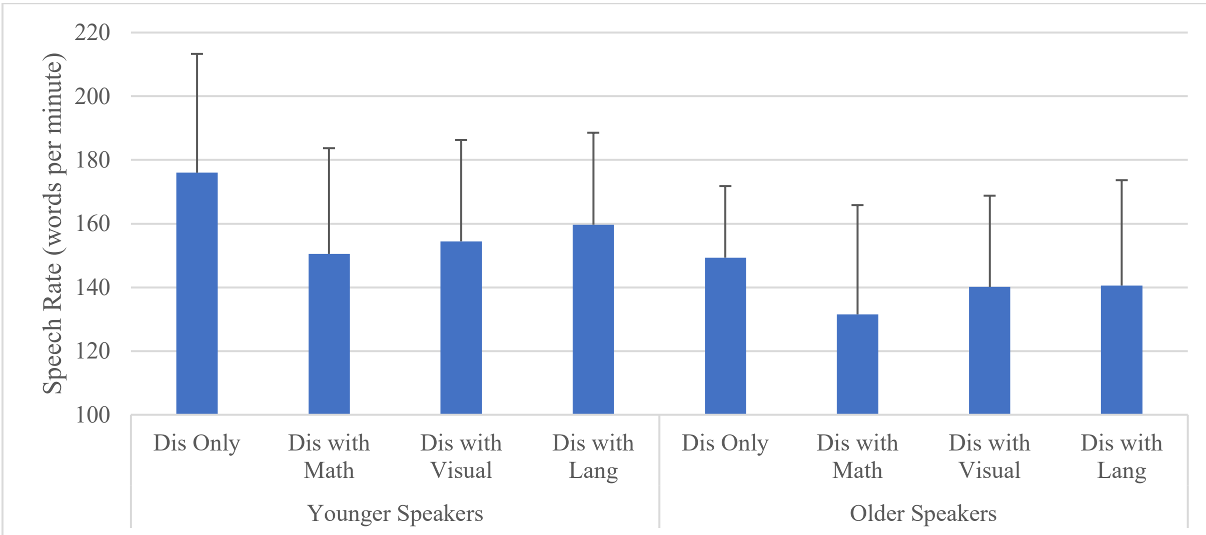
Means and Standard Deviations of Speaking Time Ratio in Discourse Condition



Note. Dis Only = discourse only; Dis with Math = discourse with mathematical; Dis with Visual = discourse with visuospatial; Dis with Lang = discourse with language.

Figure 3

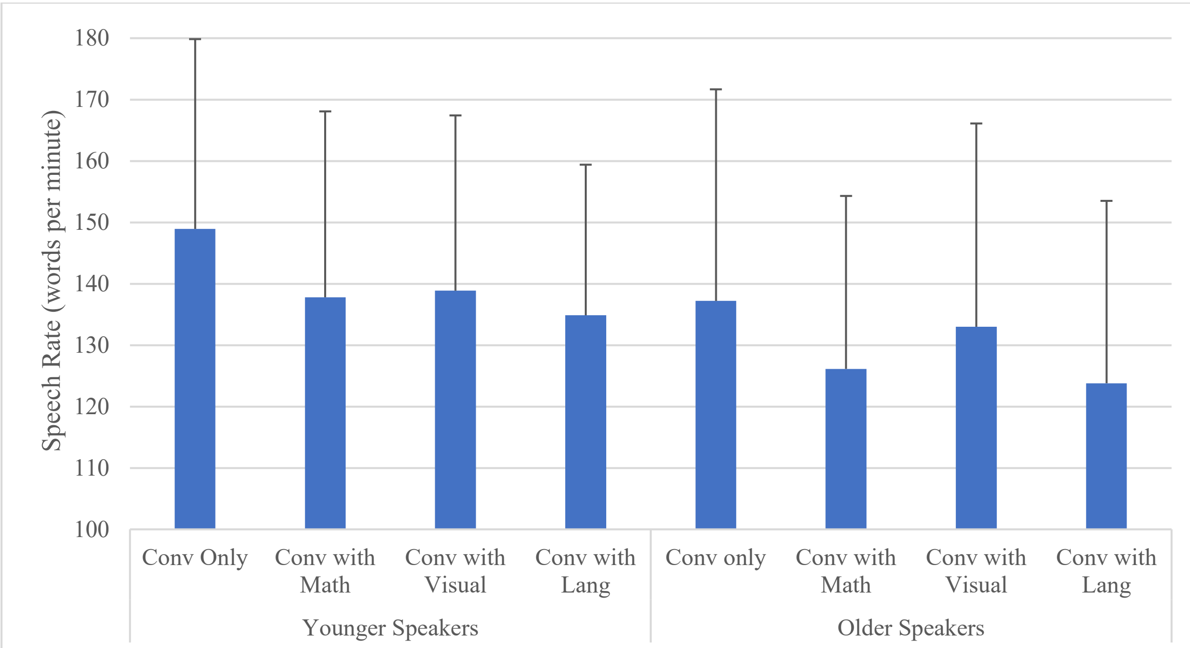
Means and Standard Deviations of Speech Rate in Discourse Condition



Note. Dis Only = discourse only; Dis with Math = discourse with mathematical; Dis with Visual = discourse with visuospatial; Dis with Lang = discourse with language.

Figure 4

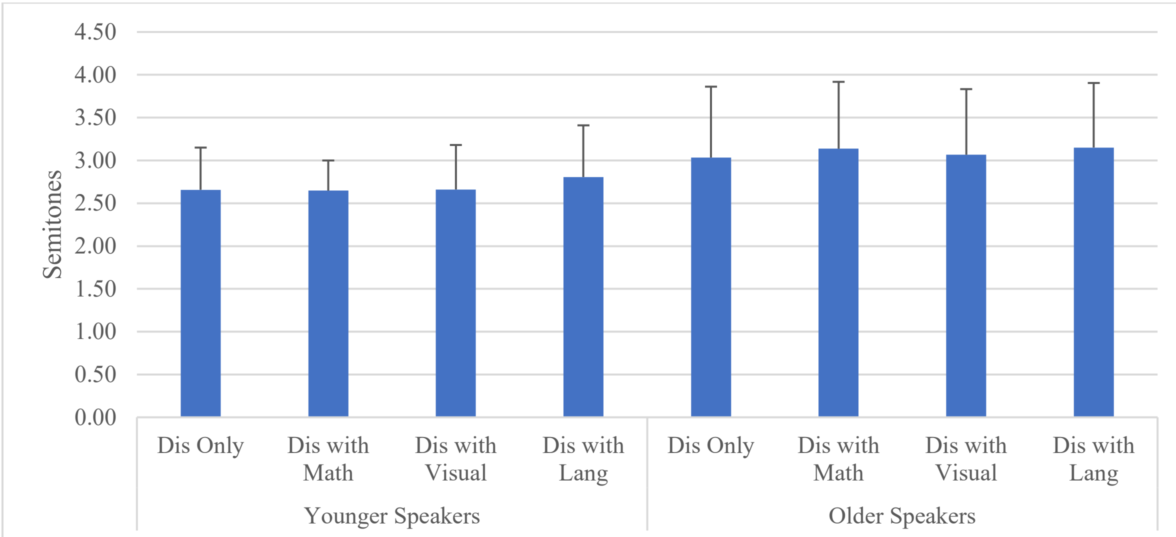
Means and Standard Deviations of Speech Rate in Conversation Condition



Note. Conv Only = conversation only; Conv with Math = conversation with mathematical; Conv with Visual = conversation with visuospatial; Conv with Lang = conversation with language.

Figure 5

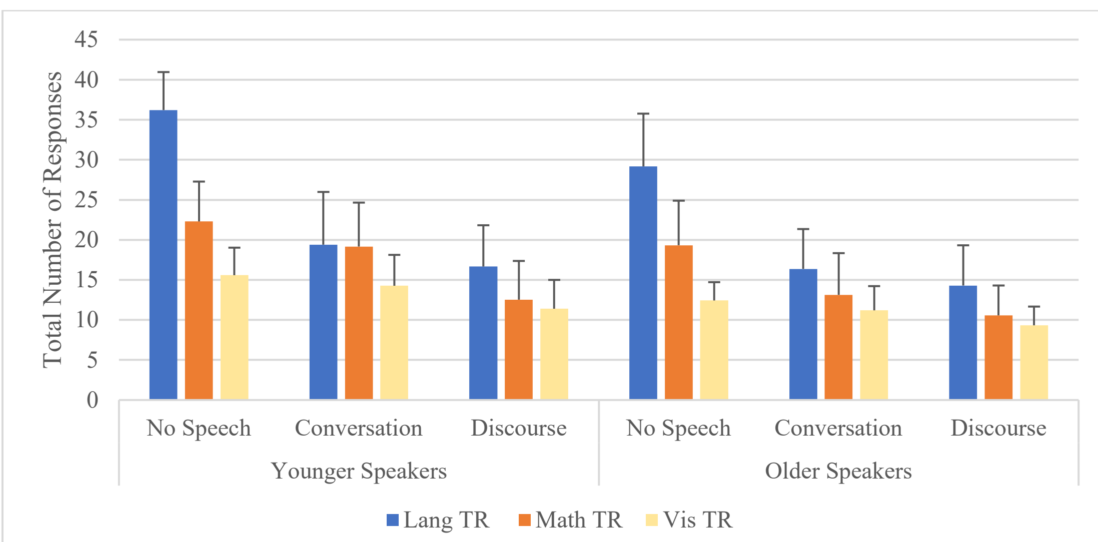
Means and Standard Deviations of Semitone Standard Deviation in Discourse Condition



Note. Dis Only = discourse only; Dis with Math = discourse with mathematical; Dis with Visual = discourse with visuospatial; Dis with Lang = discourse with language.

Figure 6

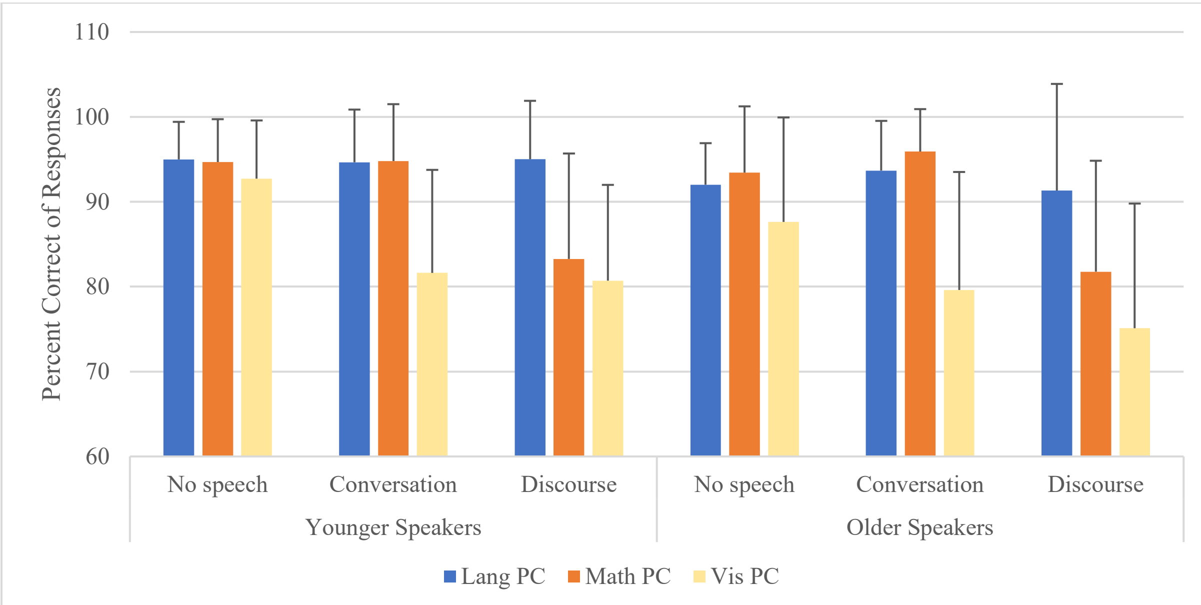
Means and Standard Deviations of Total Responses



Note. Lang TR = language total responses, Math TR = mathematical total responses, Vis TR = visuospatial total responses.

Figure 7

Means and Standard Deviations of Percent Correct of Total Responses



Note. Lang PC = language percent correct, Math PC = mathematical percent correct, Vis PC = visuospatial percent correct.

APPENDIX A

Annotated Bibliography

Bailey, D. J., & Dromey, C. (2015). Bidirectional interference between speech and nonspeech tasks in younger, middle-aged, and older adults. *Journal of Speech, Language, and Hearing Research, 58*(6), 1637-1653. https://doi.org/10.1044/2015_JSLHR-S-14-0083

Objective: The purpose of this study was to examine divided attention over a large age range by assessing the effects of three nonspeech tasks and concurrent speech motor performance on each other.

Methods: This study included 60 participants, in three age groups, with 10 males and 10 females in each. The nonspeech tasks included a semantic-decision activity, a quantity-comparison activity, a manual motor activity (the Purdue Pegboard Test), in addition to a speaking task. During the divided-attention condition, participants completed the specified task while repeating a target sentence. A lightweight head-mounted strain gauge system was used to measure the vertical movements of each participant's lips and jaw. Three cantilever beams were attached to the upper lips, lower lips, and under the chin to track the jaw and quantify the displacement and velocity signals. A microphone was attached to the headset and placed about 10 cm away from the participant's mouth to record speech. Analysis measures included utterance duration, LL displacement, LL peak velocity, UL–LL correlation, vocal intensity, and STI (a stability measure).

Results: Utterance duration, negative UL–LL correlation, and LL STI were all significantly higher during concurrent task performance. The linguistic task interfered with speech more than the cognitive task did, and data suggested that semantic decision–

making skills are better prioritized or preserved with age during divided attention than are quantity-comparison skills.

Conclusion: There is bidirectional interference between speech and other concurrent tasks as well as age effects on speech motor control. Task type plays a significant role in the stability of speech movement patterning when attention is divided.

Relevance to current study: This study uses similar non-speech tasks but with more ecologically valid speech tasks. This will help clarify whether the findings of differences between dual-task conditions are valid when using more generalizable and natural speech conditions.

Boyle, M. (2011). Discourse treatment for word retrieval impairment in aphasia: The story so far. *Aphasiology, 25*(11), 1308-1326. https://doi.org/10.1080/02687038.2011.596185

Objective: The purpose of this study was to review the literature regarding discourse treatment for those with word-finding difficulties due to aphasia.

Content: Seven data-based papers in English involving discourse treatment were reviewed. Different types of discourse are outlined – explaining an event (narrative discourse), providing directions or instructions (procedural discourse), describing something in detail (descriptive discourse), and explaining something in depth (expository discourse). All the studies in the literature review showed improved word-finding abilities after treatment involving discourse such as structured narratives. The author concluded that evidence shows discourse use in therapy is efficacious for improvements in word retrieval and should be systematically used to improve functional performance.

Relevance to current study: This study provided insight into the different types of discourse and will aid in determining what type of discourse the current study will use while collecting a speech sample.

Dipper, L. T., & Pritchard, M. (2017). Discourse: Assessment and therapy. In F. D. Fernandes (Ed.), *Advances in speech-language pathology*. InTechOpen. https://doi.org/10.5772/intechopen.69894

Objective: The purpose of this chapter was to review key developments in narrative discourse production therapy for both children and adults.

Content: Discourse is described as any unit of language that is longer than a sentence and used for a specific purpose or function. The author presents the argument that the different types of discourse will impact a speaker's everyday life according to their skills. This aids in the author's point that discourse therapy is valuable in treatment as it is widely used in everyday language. The current literature on discourse treatment and assessment is reviewed. The literature demonstrates evidence of multi-level therapies being the best approach to treating discourse and should be used with clinical judgment.

Relevance to the current study: This review provides a lengthy explanation of what discourse is, the different types of discourse, and how discourse is applied in common conversation in daily life. This information is useful when determining one of the current study's speech conditions, as discourse is a more ecologically valid speaking measure than utterance repetition.

Dromey, C., & Bates, E. (2005). Speech interactions with linguistic, cognitive, and visuomotor tasks. *Journal of Speech, Language, and Hearing Research, 48*(2), 295-305. https://doi.org/10.1044/1092-4388(2005/020)

Objective: The objective of this study was to examine if speaking while performing a linguistic task, cognitive task, or visuomotor task would lead to changes in non-speech task performance accuracy or lip movement parameters.

Methods: 10 college-aged males and 10 college-aged females with no history of speech, language, or hearing disorders participated in the experiment, which involved measuring the participants' lip and jaw movements. Seven tasks were performed in the 35–40 minute session by each participant. This included four isolated performance tasks: a speech-only task, a linguistic-only task, a cognitive-only task, and a visuomotor-only task. The participants performed each non-speech task independently and then completed the task with a concurrent speech task. Recordings were analyzed for utterance duration and lip displacement, velocity, correlation, and spatiotemporal index (STI).

Results: There was increased spatiotemporal variability of lip displacement when completing the linguistic task. The visuomotor task involved more rapid speech with smaller lip displacement. These changes suggest that different aspects of attention are required for linguistic versus manual visuomotor activity.

Conclusion: The results above indicate that there are interactions between the demands of language formulation, cognitive activity, and speech-motor performance even with typically speaking adults. This information can be used when clinicians determine goals for those clients with disordered speech – they will have difficulty with speech and multitasking as well.

Relevance to current study: This study shows that there are changes to participants' lip and jaw movements when performing language tasks, cognitive tasks, and visuomotor tasks at the same time. This provides a foundational knowledge base when determining how a more ecologically valid speaking condition will affect similar linguistic, cognitive, and visual tasks in the current study.

Dromey, C., & Benson, A. (2003). Effects of concurrent motor, linguistic, or cognitive tasks on speech motor performance. *Journal of Speech, Language, and Hearing Research, 46*(5), 1234-1246. https://doi:10.1044/1092-4388(2003/096)

Objective: The purpose of this study was to determine the effects on the lip and jaw movements of participants completing divided attention tasks.

Methods: Ten male and ten female participants were fitted with a head-mounted strain gauge system. The participants completed a speech-only task, a combined speech and motor task, a combined speech and cognitive task, and a combined speech and linguistic task.

Results: During the motor tasks, lower lip displacement and velocity decreased. During the linguistic and cognitive tasks, increased spatiotemporal variability occurred.

Conclusion: The results of this study indicated that during divided attention tasks, speech motor performance declines in labial kinematic measures.

Relevance to the current study: This study provides further evidence that speech production can be affected by the concurrent performance of other tasks.

Dromey, C., Jarvis, E., Sondrup, S., Nissen, S., Foreman, K. B., & Dibble, L. E. (2010). Bidirectional interference between speech and postural stability in individuals with Parkinson's disease. *International Journal of Speech-language Pathology*, *12*(5), 446-454. http://doi.org/10.3109/17549507.2010.485649

Objective: The purpose of this study was to examine dual-task interference between speaking and postural stability conditions in participants with Parkinson's Disease (PD).

Methods: The study involved nine individuals with PD, seven age-matched control participants, and ten young adult control participants. Participants were instructed to repeat a target utterance (targeting the corner vowels and major diphthongs) and perform a rise-to toes task, both in a single and dual-task condition. Postural stability was determined through the use of a multi-camera motion capture system and force plate recordings. Speech variables were determined through the measurement of diphthong transitions from audio recordings.

Results: Overall, the PD group experienced a greater decline in postural stability during dual-task conditions than the other groups.

Conclusion: There is greater bidirectional dual-task interference in people with PD, and this exposes individuals with PD to greater risk while completing divided attention tasks during daily activities.

Relevance to the current study: This study provides evidence that divided attention affects postural stability.

Dromey, C., & Shim, E. (2008). The effects of divided attention on speech motor, verbal fluency, and manual task performance. *Journal of Speech, Language, and Hearing Research, 51*(5), 1171-1182. https://doi:10.1044/1092-4388(2008/06-0221)

Objective: The objective of this study was to evaluate the functional distance hypothesis by examining speech, verbal fluency, and manual motor tasks.

Methods: Ten males and ten females completed a speech task, a verbal fluency task, and right- and left-handed motor tasks. All tasks were completed in isolation and concurrently with speech.

Results: During the concurrent performance of manual tasks, peak velocity, and lip displacement decreased and intensity increased. Manual motor scores decreased, and spatiotemporal variability increased when completing the motor task.

Conclusion: The findings suggest that the complexity of neural control during concurrent tasks cannot fully be explained by the functional distance hypothesis.

Relevance to the current study: This study provides further evidence that the concurrent performance of tasks can affect speech production.

Dromey, C., & Simmons, K. (2019). Bidirectional interference between simulated driving and speaking. *Journal of Speech, Language, and Hearing Research, 62*(7), 2053-2064. https://doi.org/10.1044/2018_JSLHR-S-MSC18-18-0146

Objective: The purpose of this study was to examine the interference between currently performed driving and speaking tasks.

Methods: The participants included 30 males and 30 females with no history of communication disorders, divided into three age groups. After performing practice tasks of the driving simulator, each participant completed a driving task, a monologue speech task, and a concurrent driving and speech task.

Results: The study found significant divided attention effects in speaking time ratio, intensity, speed, and steering wheel control.

Conclusion: Divided attention conditions impact both speech and driving performance.

Relevance to the current study: This study provides further understanding regarding the effects of divided attention during a dual-task performance, as well as providing insight into the effect of age in these conditions. Additionally, similar measures were used when analyzing a discourse sample.

Glenn, K. (2017). *Effects of conversational modalities on driving and speaking performance* [Master's thesis, Brigham Young University]. BYU ScholarsArchive. https://scholarsarchive.byu.edu/etd/6294/

Objective: The purpose of this study was to examine the bidirectional effects of simulated driving on conversation through the use of different speaking modalities.

Methods: Each participant completed a simulated driving task, first in isolation and then also while speaking on a hand-held cell phone, hands-free cell phone, or with a passenger in the simulated car.

Results: Intensity increased when participants were driving and speaking on the hand-held phone compared to the speaking-only condition. The participants experienced more pauses in their speech when performing the divided attention conditions than when compared to speaking alone activities.

Conclusion: The study found that there is bidirectional interference when speaking and driving.

Relevance to the current study: This study provides evidence that divided attention impacts speech when driving, supporting the need for further divided attention research.

Göthe, K., Oberauer, K., & Kliegl, R. (2007). Age differences in dual task performance after practice. *Psychology and Aging, 22*(3), 596–606. https://doi.org/10.1037/0882-7974.22.3.596

Objective: The purpose of this study was to investigate whether older adults could learn to complete two cognitive tasks at the same time without effects on performance.

Methods: This study is an extension of Oberauer and Kliegl (2004) and used their data from Experiment 1, involving an auditory and visuospatial task. They added to the previous data by including 6 more young adults and tested 12 older adults.

Results: The 6 additional young adults were able to acquire the skills needed to reach the criterion for parallel processing, which reflected the same findings from Oberauer and Kliegl (2004). None of the older adults could acquire parallel processing skills.

Conclusion: Though it is impossible to rule out the possibility that older adults just needed more practice to reach the same level of performance, the authors suggested that even moderately more practice would not have changed the results. This is due to the lack of any improvement in performance effects on trials performed by older adults. Most young adults make a transition from serial to parallel processing of two cognitive tasks with practice, at least with the present combination of tasks. Older adults do not make this transition and stay in serial processing mode.

Relevance to the current study: The study adds to the knowledge base of how older adults handle dual-task performance compared to younger adults.

Kemper, S., Hoffman, L., Schmalzried, R., Herman, R., & Kieweg, D. (2011). Tracking talking: Dual task costs of planning and producing speech for young versus older adults. *Aging, Neuropsychology, and Cognition, 18*(3), 257-279. https://doi.org/10.1080/13825585.2010.527317

Objective: This study aimed to analyze the cost of speech production in younger and older adults during a tracking motor task.

Methods: Further speech analysis was completed with speech samples taken from dual task conditions collected in an earlier study. Speech samples were segmented into utterances and then filler words ("yeah", "you know"), the number of words, the number of prepositions, pausing duration, and grammatical complexity were analyzed.

Results: Tracking performance decreased during pauses before informative, propositionally dense, grammatically complex, or long/rapid utterances. Tracking performance decreased during the production of these dense utterances. Tracking performance decreased in the pauses after these dense utterances.

Conclusion: The new analyses revealed that talking while completing a dual task has consequences on both younger and older adults' simultaneous performance on a simple visual/motor task. Adults need time to recover after a dense utterance.

Relevance to the current study: The study adds knowledge that talking while completing a visual/motor task causes bidirectional interference when trying to perform both tasks at once.

Kemper, S., Schmalzried, R., Herman, R., Leedahl, S., & Mohankumar, D. (2009). The effects of aging and dual task demands on language production. *Aging, Neuropsychology, and Cognition*, *16*(3), 241-259. https://doi.org/10.1080/13825580802438868

Objective: This study aimed to investigate the impact that dual tasks have on the language of older adults and younger adults.

Methods: 40 younger and 40 older adults participated in this study. The participants completed a pursuit rotor task, as a motor task, first by itself and then also while completing an additional task. The concurrent task included reading a prompt and answering the question while continuing to track. A baseline language sample was collected. The two questions that were used to elicit language samples included “where were you and what were you doing on 9/11?” and “describe someone you admire and why you admire them”. Each sample was analyzed for fluency, grammatical complexity, and content by trained coders.

Results: Both younger and older adults spoke more slowly to compensate for the divided attention on tasks. Younger adults experienced only a 16% decrease in speech rate, while older adults experienced a 26% decrease. Interestingly, this was the only effect that the dual-task condition had on older adults. Younger adults experienced greater costs to language, experiencing a decline in propositional content, grammatical complexity, and sentence length.

Conclusion: Language use is affected when attention is divided between a language production task and a visual-spatial tracking task. Younger adults use faster, more complex speech at baseline and therefore are more vulnerable to dual-task demands. The authors theorize that the older adults’ use of short, simple sentences with few fillers at baseline is a strategy older adults use to limit naturally occurring age-related changes. Working memory and processing speed are reduced in older adults. These limitations affect older adults’ ability to plan and produce complex, multi-clause utterances. Limitations on processing speed affect sentence planning and production aspects such as ideation and word retrieval.

Relevance to the current study: This study adds to the research base that visual-spatial tasks affect performance while speaking. It also provides insight into the effects of divided attention and aging.

Kinsbourne, M., & Hicks, R. E. (1978). Functional cerebral space: A model for overflow, transfer and interference effects in human performance: A tutorial review. In J. Requin (Ed.), *Attention and performance* (1st ed., pp. 345-362). Routledge.

Objective: This chapter introduces the functional distance hypothesis.

Content: The authors review literature related to divided attention that supports the functional distance hypothesis. This theory centers on the anatomic localization of function within the brain. This theory suggests that the interference caused by the performance of two tasks is due to the differences in the physical distances between the brain structures processing the tasks. Therefore, the degree of interference between two tasks is directly related to the distance of cerebral control centers. This model would conclude that tasks with increased similarity will involve more interference.

Relevance to the current study: This review provides background knowledge on the functional space model of attention.

McDowd, J. M., & Craik, F. I. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance, 14*(2), 267-280. https://doi.org/10.1037/0096-1523.14.2.267

Objective: The purpose of this study was to examine if age affects dual-task performance due to an increase in the difficulty of tasks.

Methods: The first experiment consisted of two visual tasks and two auditory tasks, with the only difference being that one of each task used only superficial sensory processing, whereas the other used deep cognitive processing. For the second experiment, performance was only measured with two visual tasks. Complexity was defined quantitatively: the number of choices available as two, four, or eight choices in a task.

Results: For experiment one, the authors discovered that older adults were more affected by the divided attention condition than young adults, and the task difficulty increased this penalty. For experiment two, they found that the effect of the divided attention condition decreased as the complexity of the task increased.

Conclusion: Older adults are affected by divided attention more than younger adults. This effect on performance with older adults increases as the difficulty of tasks increases. Additionally, the findings showed that divided attention can be used to increase task complexity in older adults.

Relevance to the current study: This study shows evidence that older adults are affected by divided attention more than younger adults when the tasks require deeper cognitive processes.

Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. *Psychological Review, 86*(3), 214–255. https://doi.org/10.1037/0033-295X.86.3.214

Objective: This study purpose of this study was to describe another theory that accounts for divided attention and inference.

Content: Previous publications involving frameworks of divided attention and interference were evaluated and various theoretical possibilities were analyzed to demonstrate the need for caution when interpreting data. The author introduced the concept of multiple attentional resources. The term "performance operating characteristics" (POC) is coined as a useful technique for displaying and analyzing behavior in dual-task situations but should be used with caution. The authors explain that according to this theory, dual tasks that require similar resources are going to cause more interference in tasks than those that use different types of resources.

Relevance to current study: This study provides further knowledge and understanding of the complexities of dual-task performance. Using Navon and Gopher's theory of attention allows one to build a coherent conceptual framework to help with the analysis of dual-task research, assisting in explaining theories of divided attention in the current study.

Naveh-Benjamin, M., Guez, J., & Marom, M. (2003). The effects of divided attention at encoding on item and associative memory. *Memory & Cognition*, *31*(7), 1021-1035. https://psycnet.apa.org/doi/10.3758/BF03196123

Objective: This study examined whether divided attention affects the encoding of associative memory. The authors hypothesized that poor memory occurs because of an interruption to the encoding of associative information.

Methods: The researchers completed five separate experiments with different types of episodes and episode components. Young adult graduate students completed experiments following a divided attention dual-task design. One condition consisted of a memory task and the other was either a visual or auditory continuous choice reaction time task. The memory task included memorizing word pairs for recall. Each task type was performed separately and in a divided attention condition.

Results: Divided attention resulted in a general decline in memory performance; however, performance was not poorer for association tasks than direct recall tasks, as hypothesized.

Conclusion: The results provide evidence against the hypothesis that associative memory tasks should affect memory performance more than direct recall memory tasks. It was shown that divided attention affects memory encoding overall, and the effects cannot be attributed to the associative process of memorization.

Relevance to the current study: This study provides evidence that divided attention affects memory.

Navon, D., & Miller, J. (2002). Queuing or sharing? A critical evaluation of the single-bottleneck notion. *Cognitive Psychology, 44*(3), 193-251. https://doi.org/10.1006/cogp.2001.0767

Objective: This study's purpose was to determine if the literature supports the evidence for a single-bottleneck model of attention.

Content: The current literature about the bottleneck theory was evaluated by determining possible predictions of the model calculated by computer simulations. The bottleneck theory can explain the interference relationship of simple dual tasks; however, such a specific model cannot account for the complexities and multi-faceted relationship of all types of dual tasks. The bottleneck theory is too limiting to provide a general description of dual-task interference.

Relevance to current study: This analysis describes the single-bottleneck model of attention, necessary to fully develop the understanding of theories of divided attention in the current study.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology, 7*(1), 44-64. https://doi.org/10.1016/0010-0285(75)90004-3

Objective: The purpose of this study was to examine previous literature to determine what happens when tasks are competing for single attentional resources.

Content: There are limited processing resources, and when several processes compete for the same attentional resource, it will result in an eventual deterioration of performance. A process can be limited in its performance by limited processing resources (such as memory or processing effort) or limits in the quality of data available to it. Effects depend upon the quality of data and processing resources that are being used. Essentially, when two processes use the same resource at the same time, it can cause unidirectional or bidirectional interference. There is a pool of possible resources when completing a task, and a division of processing resources occurs to allocate resources to each task. Interference occurs when the available resources are insufficient for both tasks. The author concludes with the proposal that it is necessary to distinguish between resource-limited operations and data-limited operations to fully understand the performance-resource function.

Relevance to the current study: This study will provide background in understanding the theories of attention.

Simmons-Mackie, N., Elman, R. J., Holland, A. L., & Damico, J. S. (2007). Management of discourse in group therapy for aphasia. *Topics in Language Disorders*, *27*(1), 5–23. https://doi.org/10.1097/00011363-200701000-00003

Objective: The purpose of this study was to gain information about the interaction patterns and management of discourse strategies to help define “conversation” or “social” group therapy for aphasia.

Methods: This study consisted of six group therapy sessions including participants with aphasia and clinicians. All individuals participated in common conversation topics led by therapists subtly managing discourse structure, which were videotaped and analyzed. Through these group therapy sessions, discourse management features were evaluated. For example, an important aspect of these sessions was clinician-directed discourse with the avoidance of any rigid, structured discourse. Previously, literature about aphasia discourse described aphasia therapy as controlled, with planned tasks, allocating turns, and eliciting responses.

Results: The patterns identified in these conversation groups were found to differ from patterns of discourse commonly recognized in traditional impairment-focused therapy. Some of these differences included establishing discourse equality, focusing on everyday communicative events and genres, and employing multiple communication modes.

Conclusion: The results indicated that these differences improved therapy effectiveness by improving communicative skills, increasing communicative confidence, and helping the participants implement communicative strategies

Relevance to the current study: This study provides an evidence base for the importance of naturalistic speaking conditions in therapy with less structure. This concept contributes to the understanding that natural discourse can be a tool used in the current study to increase ecological validity compared to repetitive speech tasks.

Verhaeghen, P., Steitz, D. W., Sliwinski, M. J., & Cerella, J. (2003). Aging and dual task performance: A meta-analysis. *Psychology and Aging*, *18*(3), 443–460. https://doi.org/10.1037/0882-7974.18.3.443

Objective: The purpose of this study was to examine the relationship between dual-task effects and aging through a meta-analysis of 33 studies.

Methods: Effects on performance were measured through reaction time and accuracy. The two types of graphical analysis (State-Trace analysis and Brinley analysis) were applied to the data using hierarchical linear modeling. For state-trace analysis, the mean latency data of dual-task conditions were regressed on the mean latency data of single-task conditions. This provided information on whether there was any age difference between younger and older adults. For the Brinley analysis on latency, the mean performance of older adults was regressed on the mean performance of younger adults.

Results: As for the latency measure, multilevel modeling of the state-trace analysis demonstrated that dual-task costs in both younger and older adults are additive (meaning that performing a concurrent second task added "a fixed cost" to the latency of the first task). Additionally, state trace showed that the dual task cost for the young in the data set was 17% and the old was 26%. As for the accuracy measure, there was no evidence for age-related differences in either single or dual-task performance.

Conclusion: There is a significant age-related deficit in dual-task performance when it comes to latency. The state-trace analysis demonstrated that the dual-tasking condition took about twice as long in older adults as in younger adults.

Relevance to the current study: This meta-analysis found that older adults had a slower reaction time than younger adults. However, this study also concluded that no specific age deficit is associated with effects on accuracy. This study provides evidence for the current study's hypothesis related to aging effects.

Wickens, C. D. (1981). *Processing resources in attention dual task performance, and workload assessment* [Technical Report EPL-91-3/ONR-81-3]. Office of Naval Research Engineering Psychology Program. https://apps.dtic.mil/sti/tr/pdf/ADA102719.pdf

Objective: The objective of this study was to outline theories of divided attention including structural and capacity theories and to contrast them.

Content: The author reviews various studies discussing structural theory and explains that differences in task structure or stages of processing impact dual-task conditions. The author states that these theorists acknowledge that there is a role of task difficulty in generating interference, as more difficult tasks occupy the bottleneck for a longer duration than easier tasks. This is an idea commonly found in capacity theories. The author then discusses capacity theories, explaining the concept of having a limited capacity – when concurrently performing two tasks at once, attentional resources are limited, and as one task becomes more difficult (or demands more attentional resources) performance in the secondary task declines. The author notes that structural theories argue processing can only occur one item at a time, whereas capacity theories suggest that capacity can be "allocated" between two separate activities.

Relevance to the current study: This study provides foundational knowledge regarding theories of attention and will be used to discuss processes of attention under dual-task conditions.

Wickens, C. D. (2008). Multiple Resources and mental workload. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *50*(3), 449–455. https://doi.org/10.1518/001872008x288394

Objective: The purpose of this study was to provide a rationale for the multiple resource theory and the 4D multiple resource model.

Content: The author describes previous versions of the multiple resource theory as well as developments to the model to explain dual-task performance. The four dimensions are then explained, the author describing how its relevance to performance is due to how performance breakdowns are related to dual-task overload. This can be revealed by comparing the demands both tasks share, and the extent to which both share common levels for each of the four dimensions. The author describes the differences between the multiple resource model and mental workload. The multiple-resource model is characterized by demand, resource overlap, and allocation. Workload relates most greatly with demand, described as the demand imposed by tasks on limited resources.

Relevance to the current study: This article provides a further framework on the multiple attention model and provides background to the theories of attention.

APPENDIX B

Institutional Review Board Approved Consent

Consent to be a Research Subject

Title of the Research Study: Effects of Concurrent Computer Use on Speech Acoustics and Physiologic Arousal
Principal Investigator: Christopher Dromey, PhD
IRB ID#:

Introduction

This research study is being conducted by Professor Christopher Dromey, assisted by Tiana Bateman, Chanelle Thomas, and Paige Snow from the Department of Communication Disorders at Brigham Young University, to determine how speaking while completing another task can influence both the way a person speaks and how well they complete the other task. You were invited to participate because you are a native speaker of American English and have no history of speech, language, or hearing disorders.

Procedures

If you agree to participate in this research study, the following will occur:

- you will sit in a sound-treated booth in room 106 of the John Taylor Building for a recording session
- you will complete a brief hearing screening
- you will wear a headset microphone to record your speech
- you will have sensors attached to your foot to measure skin responses associated with stress
- you will be handed 3 small electrodes and asked to attach them to yourself near your collar bone and stomach
- you will read aloud sentences that will be presented on a computer screen in front of you
- you will be asked to describe how to complete a task, such as making a sandwich or carry on a conversation with the experimenter
- you will complete some computer-based tasks, such as formatting text, responding to yes/no questions about sentence accuracy or simple math problems
- sometimes you will be speaking while you do nothing else; sometimes you will be speaking at the same time you are working on a computer task
- total time commitment will be 60 minutes in one recording session

Risks/Discomforts

No risks are associated with the study beyond that experienced in everyday life. You might feel fatigued during the session, especially while multitasking.

You may take a break at any time during the study to rest. If the audio recordings were to be exposed to a breach of privacy, they will not have your name associated with them and will only involve everyday topics of conversation. See the Confidentiality section below.

Benefits

There will be no direct benefits to you as a participant. However, we anticipate that the findings from this study will benefit the field of speech pathology by helping us design better treatments for people with speech problems.

Confidentiality

The research data will be kept on password protected computer and only the researchers will have access to the data. Before we analyze the recordings, all identifying information will be removed so that your name will not be linked to the recordings. Only summary data from groups of participants will be reported in publications and presentations. After the study the de-identified data will be kept on a password-protected computer in the researcher's office for possible future analysis with new techniques.

Compensation

You will receive $10 for your participation, whether you finish the recording or not; compensation will not be prorated.

Participation

Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely without jeopardy to your class status, grade, or standing with the university.

Questions about the Research

If you have questions regarding this study, you may contact Christopher Dromey at 133 TLRB, 801-422-6461, dromey@byu.edu for further information.

Questions about Your Rights as Research Participants

If you have questions regarding your rights as a research participant contact IRB Administrator at (801) 422-1461; A-285 ASB, Brigham Young University, Provo, UT 84602; irb@byu.edu.

Statement of Consent

I have read, understood, and received a copy of the above consent and desire of my own free will to participate in this study.

Name (Printed): ________________ Signature: _______________________ Date: ____________

APPENDIX C

List of Possible Procedural Discourse Prompts

1. You are flying to another country. Explain the process required to board the plane, starting from the entrance to the airport.
2. You land in a large airport after a long flight and upon arrival at the baggage claim, your bag is not there. Explain the steps you would take to find your bag.
3. You get rear-ended by another car at a traffic light. Explain what you would do and what you would need to do.
4. You finally get to take your dream vacation out of the country. Explain the necessary steps you would take to plan and prepare for this vacation.
5. Explain the steps necessary to plan a birthday party for a 6-year-old.
6. Explain the steps necessary to plan an elementary school field trip to the zoo.
7. Your car keeps overheating, Explain the steps you would take to get your car repaired.
8. You are interested in buying a house. Explain the steps you would need to take to make this happen.
9. You need a new job. Explain the steps you would take to find and acquire a new job.
10. You have decided to take your young nieces and nephews on a trip to an amusement park. Describe the steps you would need to take to plan and prepare for your trip.
11. Explain the steps involved in opening a new bank account, depositing money into the account, and withdrawing money from the account, as if I had never done it before.
12. Explain the process of finding and purchasing groceries at a grocery store.
13. Tell me the steps for writing and sending a thank you letter.
14. Explain what you would do if you discovered you had a flat tire while driving on the freeway.
15. You are asked to write a research essay on a topic that interests you. Explain the process required to write a good essay.
16. You decide to plant a garden. Explain the steps you would take to plan for and plant your garden.
17. You want to save money for a big purchase. Describe the steps you would take to create and maintain a budget.
18. Explain the steps you would need to take to start a new business.
19. Explain the process of making your favorite dessert or meal.
20. Explain how to play your favorite board or card game.
21. Explain how to play your favorite sport.

APPENDIX D

List of Possible Conversation Prompts

1. Where are you from? Where did you grow up?
2. What do/did you do for a living?
3. What are you studying in school?
4. Tell me about your family.
5. Tell me about some of your favorite hobbies.
6. What is one of your favorite places you’ve traveled to?