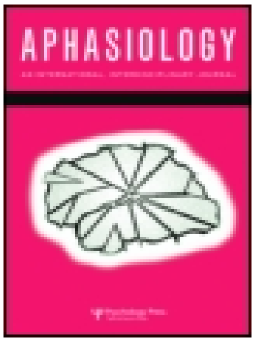

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A dual-task tool for quantifying normal comprehension of aphasic connected speech production: A constructive replication

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Background: Deficits of attention or its control secondary to brain damage have been proposed as all or part of the underlying mechanisms for the linguistic impairments that characterise aphasia (Clark & Robin, 1995; Granier, Robin, Shapiro, Peach, & Zimba, 2000; McNeil, 1982, 1988; McNeil, Odell, & Tseng, 1991; Murray, Holland, & Beeson, 1997a; Tseng, McNeil, & Milenkovic, 1993). McNeil, Doyle, Hula, Rubinsky, Fossett, and Matthews (2004) developed a set of tasks to quantify the difficulty that normal listeners have in understanding the language production of persons with varying amounts of aphasia. In their dual-task study, a significant decrement was found in the visual–manual tracking accuracy of normal older individuals while concurrently listening to the connected language of a person with moderate, as compared to mild, aphasia. No performance costs were observed on the listening tasks across three tracking difficulty levels. Possible reasons for the unidirectional performance cost were speculated and the present study was designed to investigate one of them.

Aims: Using the same story comprehension task used in the previous study and the same visual–manual tracking task, but increased in difficulty, this study sought to investigate whether the increased demands of the tracking task were sufficient to elicit a concurrent cost on story comprehension performance.

Methods & Procedures: A total of 24 normal participants performed the tracking and story comprehension tasks concurrently and in isolation. Story retell performance was evaluated within subjects across two tracking difficulty levels (easy and hard) and tracking performance was evaluated between subjects across three story difficulty levels (no story, mild difficulty, and moderate difficulty).

Outcomes & Results: Tracking performance varied significantly across story task difficulty in the easy tracking condition, with participants demonstrating better tracking performance in the mild story condition than in either the moderate story or no story conditions. None of the comparisons made with the harder tracking condition reached significance. There was no effect of tracking difficulty on story comprehension as measured by subsequent story retell performance.

Conclusions: The findings from this study replicate the findings from the McNeil et al. (2004) study that these dual-tasks show a reliable cost of story difficulty on concurrent tracking performance. Contrary to predictions, no effect of tracking difficulty on story retell

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performance was found, despite the increased tracking difficulty used compared to the previous study. While this finding does diminish the probability that insufficient tracking task difficulty was the source of the unidirectional costs in the previous study, it leaves a number of alternative explanations for the findings viable and unaddressed.

The terms attention, capacity, cognitive effort, and processing resources are used interchangeably to describe the fuel or activation required to perform cognitive operations. Resource models of attention vary along a number of parameters, including most notably whether there is a single pool of resources that can be flexibly allocated to multiple tasks (Kahneman, 1973) or whether there are dedicated pools of resources that are computationally specific (Gopher, Brickner, & Navon, 1982; Navon & Gopher, 1979, 1980; Wickens, 1984). What these models have in common is the notion that attention is capacity-constrained and can be distributed in a graded fashion to accomplish all cognitive processing for which it is required (i.e., attention demanding).

Traditionally, investigations of cognitive effort that have been motivated from a resource allocation perspective utilise dual-task methods to index decrements in the performance of one task as a measure of the processing load of a concurrent task (Arvedson & McNeil, 1987; Campbell & McNeil, 1985; Erickson, Goldinger, & LaPointe, 1996; Gopher et al., 1982; Granier et al., 2000; Murray, 2000; Murray, Holland & Beeson, 1997a, 1997b, 1998; Navon, 1990; Slansky & McNeil, 1997; Tseng et al., 1993; Wickens, 1976, 1986). Predictions regarding performance trades are similar whether considering a single or multiple pool resource model; however, the cause of the observed effects differs. For instance, a bidirectional performance cost is hypothesised to occur from a single resource model perspective because manipulation of Task A difficulty affects not only Task A but Task B as well, as resources to perform both tasks are drawn from a common resource-limited pool (Kahneman, 1973). A bidirectional performance cost is only observed from a multiple resource pool perspective when the difficulty manipulations for both tasks affect resource pools utilised by both tasks (Navon & Gopher, 1979, 1980).

Dual-task studies can be classified into three main categories according to their methods, including single-to-dual-task subtraction, voluntary effort allocation, and concurrent task difficulty manipulation. In the single-to-dual-task subtraction method, comparisons are made between the performance levels of each task in isolation and then when the tasks are performed concurrently. According to this method, sharing of a limited-capacity resource is inferred when performance decrements are observed in the dual-task condition (Erickson et al., 1996; Murray, 2000; Murray, Holland & Beeson, 1997a, 1997b, 1998). Navon and Gopher (1979) identified substantial limitations of this method, including assumptions that task demands, specifically the structures and processes recruited, are equivalent in dual-task conditions to the combinations of the single tasks; also, that equal attentional capacity is available in both single- and dual-task conditions. The voluntary effort allocation method avoids the assumptions made in the subtraction method, but poses additional challenges due to the possibility that participants may not allocate effort according to instructed allocation ratios. Participants are instructed to allocate their available resources in varying amounts to each of the two tasks and a performance operating curve (POC) is plotted to describe the limits of concurrent task performance on the two tasks (Navon & Gopher, 1979). Navon (1984) suggested that one risk of this method is that the performance trade between the two tasks may not be an accurate account of shared resources, but rather a reflection of subject bias or attempts to please the investigator by meeting performance expectations. In the concurrent task difficulty manipulation procedure, participants perform two concurrent tasks whose difficulties are systematically and independently manipulated but whose effort is allocated fully and equally between the two tasks (Campbell & McNeil, 1985; Hirst & Kalmar, 1987; McLeod, 1977; Payne, Peters, Birkmire, Bonto, Anastasi, & Wenger, 1994; Wickens, 1986; Wickens, Kramer, Vanasse, & Donchin, 1983). If resources are shared, increasing the difficulty of one task should cause a performance decrement in both tasks. This method can be used in conjunction with the voluntary effort allocation method or with the single-to-dual-task subtraction method.

Attentional impairments secondary to brain damage have been proposed to be all or part of the underlying mechanisms which account for the linguistic impairments that characterise aphasia (Clark & Robin, 1995; Granier et al., 2000; McNeil, 1988; McNeil et al., 1991; Murray et al., 1997a; Tseng et al., 1993). As an initial step in the development of a tool to quantify linguistic performance deficits in aphasia resulting from impairments of resource allocation, McNeil et al. (2004) conducted a series of experiments to describe the measurement properties of a linguistic and non-linguistic task for indexing resource allocation demands of both tasks. They used dual-task methods to quantify the effort expended by non-brain-damaged persons in comprehending connected speech produced by persons with aphasia. Resource allocation theory served as the theoretical foundation for this study and the others in this series. In the fourth of this series of studies, an equal priority concurrent task difficulty manipulation was used, whereby the difficulty levels of a story comprehension task and a non-linguistic visual–manual tracking task were systematically and independently manipulated. Although there are a number of limitations in doing so, single-task performance was compared to dual-task performance in this study in order to facilitate comparison of these data with those of other studies that have used single to dual task comparisons. In this series of experiments, McNeil et al. (2004) established four levels of listening difficulty for the Story Retell Procedure (SRP) (McNeil, Doyle, Fossett, Park, & Goda, 2001), established the stability of a visual–manual tracking task, and provided evidence supporting the use of these two tasks for indexing concurrent performance costs as a measure of attentional resource utilised in comprehending the connected speech of persons with aphasia by non-brain-damaged listeners (McNeil et al., 2004).

Findings obtained from the last experiment in this series were interpreted as support for the use of these concurrently performed tasks to index the spoken language handicap in aphasia. This was accomplished by quantifying the information retold from the story as measured by the percentage of the information units per minute (%IUs/Min) and by the visual–manual tracking task performance indexed by the root mean square (RMS) error. Under ideal conditions, resource theory would predict a bidirectional performance trade (McNeil et al., 1991; Murray, 1999). Specifically, as the difficulty of one of the tasks increases or decreases, performance on the other task would suffer or improve accordingly. Its presence would provide support that the computations required for performing both of these tasks share limited attentional resources. However, a bidirectional performance cost was not observed in the McNeil et al. (2004) study. Rather only an effect of story difficulty on tracking performance was observed in the dual-task condition. Furthermore, this performance cost was only observed across a limited range of story difficulty levels (i.e., stories of mild and moderate difficulty).

Proposed post-hoc explanations for these findings addressed both methodological and theoretical factors. Methodological factors included issues related to the off-line measurement of the language comprehension task (i.e., the SRP), the continuousness versus the discreteness of the tasks, and the disparity in the grain size of analysis for each of the two tasks (i.e., the continuous and fine-grained measurement of the tracking task versus potentially intermittent and course grain of the SRP task using the %IU/min as the dependent variable), redundancy of connected language allowing attention to be diverted to the tracking task when needed without an observed decrement in language performance, and that the tracking task may not have been sufficiently attention demanding to interfere with the language task. Theoretical factors included the possibility of partially overlapping sets of resource pools (Navon & Gopher, 1980) where perhaps only the language task challenged the shared pools, or where the tracking task may have affected a motor-specific pool not utilised in the language task.

The purpose of this constructive replication was to address the specific issue of tracking difficulty. It was hypothesised that the tracking levels utilised in the original dual-task study may not have been sufficiently ‘‘attention demanding’’ to interfere with the story comprehension task. In order to further investigate this hypothesis, the two story levels shown in the original study to affect a cost on tracking performance, and one tracking difficulty level greater than that used in the original study, were employed in a dual-task experiment to elicit a bidirectional performance trade. It was hypothesised that the increased visual manual tracking task difficulty would be sufficient to demonstrate a concurrent performance cost on the listening task that was not evidenced in the original study (McNeil et al., 2004).

METHOD

Participants

A total of 24 non-brain-injured individuals between the ages of 40 and 72 years (mean = 53.9; *SD* = 8.9) participated in the study (see Table 1 for participant data and screening criteria). Selection criteria included negative self-reported history of neurological, communication, or psychiatric disorders; passing a pure tone hearing screening at 35dB HL in one ear at .5, 1, 2, and 3K Hz; 20/80 vision or better measured with the reduced Snellen chart; and a minimum of 12 years of education. Table 1 displays age and language performance for each participant. All screening and experimental data were obtained in either a single session lasting no more than 3 hours, or in two sessions of shorter duration, conducted within 7 days of one another.

Procedure

Participants performed the visual–manual tracking task under two conditions delivered via the RAPP (Resource Allocation Paradigms of Pittsburgh) software program (McNeil et al., 2004). In the first condition, participants performed the tracking task in isolation. In the second, they performed the tracking task while concurrently listening to stories from the SRP (McNeil et al., 2001). Dual-task tracking was performed under four different conditions where the difficulty of both the listening (mild and moderate story difficulty levels) and tracking (easy and hard) tasks was parametrically manipulated, yielding a total of 12 dual-task trials for each participant. Participants were instructed to give their full and equal attention to both tasks.

The tracking task required the participants to manually control a cross-hair using a joystick with their dominant (right) hand. Participants maintained the cross-hair on an unpredictably varying waveform that scrolled across the computer screen at preset speeds, amplitudes, and frequencies (turnarounds). In order to make the tracking tasks more difficult than those used in the previous study, the horizontal plane of the viewing window was reduced to 10% of the original size, to reduce the participants’ ability to

TABLE 1
Descriptive participant data and inclusion criteria

Subject	*Age*	*RTT[a] percentile*	*SPICA[b] percentile*	*ABCD[c] ratio*
1	48	62	60	1.13
2	49	58	35	1.15
5	44	80	55	1.0
6	67	55	95	1.0
7	45	67	5	1.06
8	55	27	90	1.06
9	49	53	50	0.94
10	41	50	95	1.0
11	44	21	30	1.0
12	43	81	99	0.88
13	58	78	85	1.0
15	64	84	75	1.06
16	56	80	45	1.07
17	59	56	30	1.0
18	52	62	75	1.0
19	55	28	85	1.0
21	53	82	55	1.0
22	64	78	55	1.0
23	68	22	80	1.0
24	56	38	5	0.93
25	58	19	55	1.07
26	72	79	20	0.92
27	53	53	35	0.92
28	40	65	35	1.0
Inclusion Criteria:	40–75	≥ 5th %ile for normal adults	≥ 5th %ile for normal adults	within 2 SD of normal adults (.68–1.24)[d]
Mean	53.88	57.42	56.21	1.07
SD	8.88	21.59	28.27	0.06
Range	40–72	19-84	5-99	0.88–1.15

[a] Revised Token Test (McNeil, 1978)
[b] Shortened Porch Index of Communicative Ability (DiSimoni, Keith, & Darley, 1980); norms for non-brain-injured persons (Duffy & Keith, 1980).
[c] Arizona Battery of Communication Disorders of Dementia Immediate to Delayed Story Retell Performance (Bayles & Tomoeda, 1993).
[d] ABCD Normative Data (Bayles, Boone, Tomoeda, Slauson, & Kaszniak, 1989).

predict the upcoming wave and preplan their response. The easier tracking condition in the current study was the difficult condition in the previous study (100% wave amplitude and turnaround frequency of 180 vertices per minute). The more difficult condition in the current study was constructed by increasing the frequency of directional changes in the wave compared to the easier condition (100% wave amplitude and turnaround frequency of 220 vertices per minute). Wave scroll speed was held constant in all conditions in both studies.

In an effort to minimise warm-up and practice effects across experimental conditions, participants performed 12 two-minute tracking-only trials prior to the single-task tracking condition. The presentation order of the practice trials was counterbalanced, so that each participant tracked six 2-minute waves at each of the two difficulty conditions in a randomised order. These trials were not analysed. The number of practice tracking trials was determined by a previous study that quantified the amount of tracking trials required to eliminate the practice effects across the visual manual tracking task conditions (McNeil et al., 2004). Following the practice trials and prior to the dual-task conditions, all participants performed three single-task tracking trials, counterbalanced by difficulty level, at one of the two tracking difficulty conditions. Following the dual-task conditions, they then performed three single-task tracking trials at the alternate tracking difficulty level.

The listening task used for this study was the Story Retell Procedure (SRP), which has been shown to be a reliable, valid, and sensitive index of connected speech comprehension/production performance in adults with and without aphasia (McNeil et al., 2001; McNeil, Doyle, Park, Fossett, & Brodsky, 2002). Under the dual-task conditions, each participant heard six stories produced by persons with mild aphasia (mild difficulty—three stories paired with each tracking difficulty condition) and six stories produced by persons with moderate aphasia (moderate difficulty—three stories paired with each tracking condition). Stories were randomly assigned to each participant and counterbalanced so that each set of three stories was represented an equal number of times across story difficulty and tracking difficulty levels. Following each story in the dual-task condition, the participants stopped tracking and retold the story in their own words. The retellings were digitally recorded and subsequently scored for %IUs/Min. As in all previous studies, an IU was defined as ''. . . an identified word, phrase, or acceptable alternative from the story stimulus that is intelligible and informative and that conveys accurate and relevant information about the story'' (McNeil et al., 2001, p. 994). The %IU/Min score was calculated by first tallying the number of IUs, and then dividing the sum by the number of IUs available in the original story. This measure of information transfer (%IUs) was then divided by the number of minutes taken to produce the retell. The %IU/Min metric served as the *efficiency* measure of information transfer.

Concurrent performance costs were evaluated by analysing the data with two two-way repeated measures ANOVAs, one each with root means square (RMS) tracking error and %IUs/Min as the dependent variables. The three levels of story difficulty (no story, mild difficulty, and moderate difficulty) was a within-groups factor, and the two levels of tracking difficulty was a between-groups factor for both analyses. Alpha levels were set at $p < .05$ for all comparisons.

RESULTS

The analysis of tracking performance revealed significant main effects ($p < .05$) for both tracking difficulty level, $F(1,23) = 14.91$, $p = .001$, and story difficulty level, $F(2,22) = 9.361$, $p = .001$, and a significant interaction, $F(2,22) = 22.83$, $p < .001$. As expected, tracking error was significantly lower in the easier tracking condition compared to the harder tracking condition. Also as expected, there was a significant main effect of story difficulty level on story retell performance, $F(1,23) = 87.16$, $p < .001$. Participants produced significantly more %IUs/Min in the mild story difficulty condition than in the moderate difficulty story condition.

Given the presence of the significant interaction in the analysis of tracking performance, post hoc analyses were carried out using the Bonferroni adjustment for multiple comparisons ($\alpha = .05/3 = .017$) to test for significant contrasts among the three story difficulty levels at both tracking difficulty levels. None of the comparisons made with the harder tracking condition reached significance. However, analysis of the effect of story difficulty level on the easier tracking condition revealed significantly better tracking performance in the dual-task condition with the story of mild difficulty compared to the dual-task condition with the story of moderate difficulty. All 24 participants' tracking performance demonstrated this pattern of increased tracking error in the dual-task condition with the story of moderate difficulty compared with the story of mild difficulty. Participants' tracking performance was also significantly better in the dual-task condition with mild story difficulty than in the non-competitive tracking condition, with 22 of the 24 participants' tracking performance demonstrating this pattern. The effects of tracking and story difficulty level are illustrated in Figure 1.

As illustrated in Figure 2, neither tracking difficulty level, $F(1,23) = 3.54$, $p = .073$, nor the interaction between story and tracking difficulty levels, $F(1,23) = 0.631$, $p = .435$, resulted in statistically significant differences in story retell performance as measured by %IUs/Min.

DISCUSSION

This study represents a constructive replication of McNeil et al. (2004) and was motivated by the finding reported in that study that only the SRP difficulty manipulations resulted in significant performance changes in the visual–manual tracking/SRP dual-task

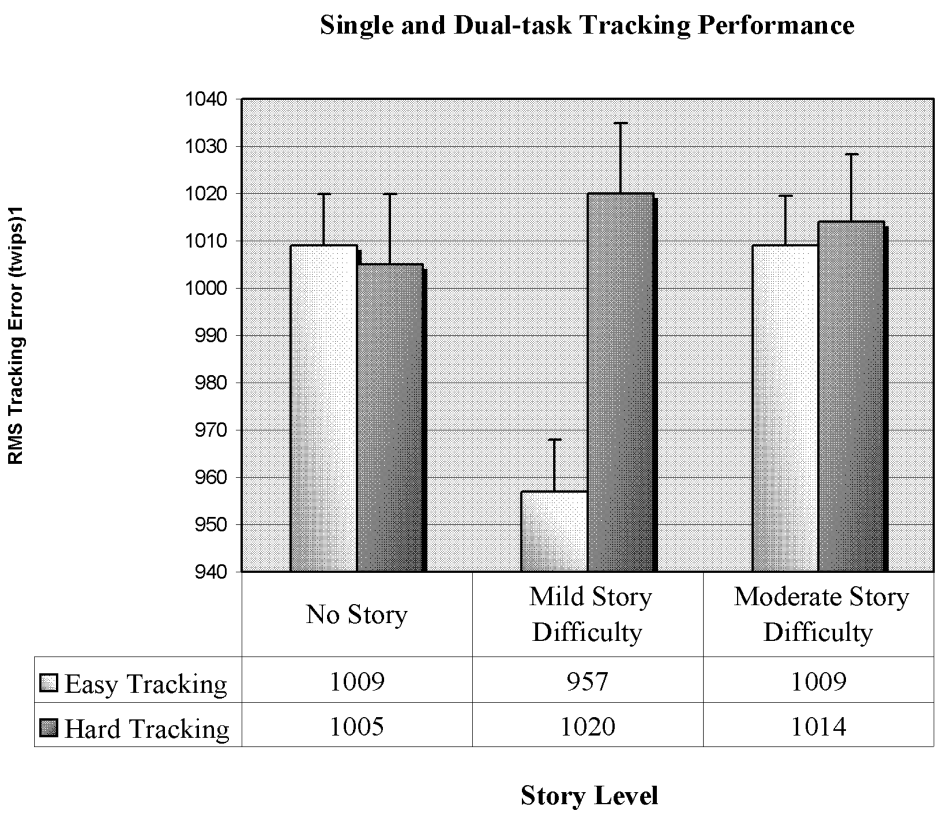
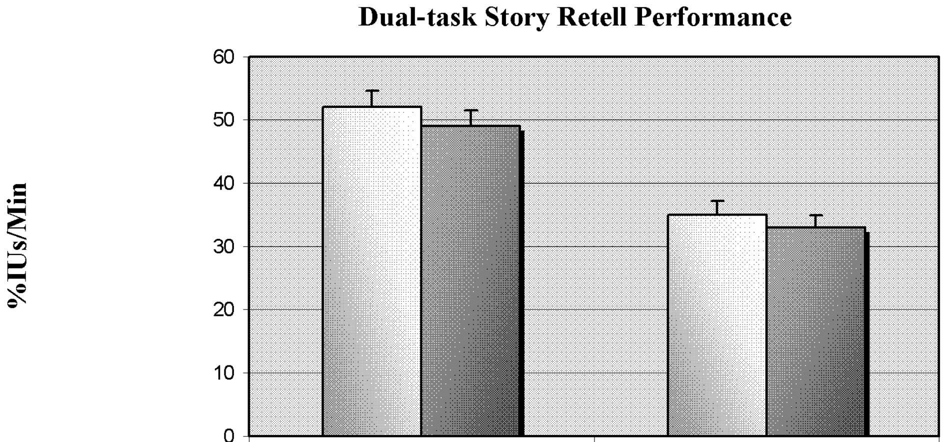


Figure 1. Tracking performance during single and dual-task tracking with two story difficulty levels across two tracking difficulty levels. (A twip is a standardised pixel, defined as 1/1140th of a logical inch.)



	Mild Story Difficulty Level	Moderate Story Difficulty Level
Hard Tracking	52	35
Easy Tracking	49	33

Story Level

Figure 2. Effect of tracking difficulty on story retell performance.

procedure. McNeil et al. (2004) hypothesised that the visual–manual tracking tasks used were insufficiently difficult to incur a performance cost on the SRP. In order to investigate the nature of this unidirectional performance cost, the difficulty of the tracking task was increased in the current study and paired with the two story difficulty levels that had produced the greatest costs to tracking in the previous study. The complexity of the tracking task was increased by increasing the number of directional changes per unit of time and by decreasing the horizontal dimension to 10% of the viewing window used in the original experiment. By increasing the difficulty in these ways, it was hypothesised that the tracking task would be more cognitively and motorically demanding. Indeed, the proposed benefit of spatial and/or temporal prediction (Rosenbaum, 1980; Schmidt & Gordan, 1977) may have contributed to insufficient demands on attention during the previous study to incur a performance cost on the language task. By decreasing the amount of the viewable wave prior to executing the motor movements for tracking the wave, it was hypothesised that less pre-planning and anticipation of tracking strategies could occur, thus increasing the cognitive demands of tracking the wave as it scrolled across the computer screen.

While these task changes did appear to increase tracking error, the increased task demands did not yield the predicted bidirectional performance costs. Although this finding does diminish the probability that low tracking task difficulty was the source of the unidirectional costs in the previous study, it does leave a number of alternative explanations viable and unaddressed. The cost to tracking as a consequence of concurrent story difficulty is consistent with the notion that the processing resources utilised during language processing may be drawn from a pool that is shared with the visual–manual tracking task when the task demands exceed those available to the dedicated pool, but that those dedicated to visual–manual tracking are not available to the language processing regardless of task demands. Such a partially overlapping set of resource pools (Navon & Gopher, 1980) would be consistent with the notion that the manipulation of the story retell task challenged the available processing resources of both tasks, whereas the tracking task did not. Consistent with this explanation is the finding derived from dual-task studies employing event-related potential methods. These studies (Backs, 1997; Isreal, Chesney, Wickens, & Donchin, 1980; Kahneman, 1973) suggest that manipulating the frequency of the wave in the visual–manual tracking task does not place an additional load on the perceptual and central processes utilised by the language processing task, at least those measured by P300 amplitude elicited with an oddball secondary task. Again, these findings are consistent with the notion that there is a pool of resources dedicated to visual–manual tracking that could have been exhausted by the tracking difficulty manipulation and by the language processing demands, but which was unavailable to aid the depleted language processing resources, causing the observed unidirectional performance cost.

The significant finding that the costs to tracking performance occurred only under the easier of the two story difficulty conditions requires explanation or speculation. It might be expected that there would be an even greater cost to tracking with the moderate story difficulty level compared to the mild one. Perhaps the most parsimonious explanation for this finding is that the participants evaluated the task demands to be sufficiently greater during the dual-task conditions and were able to ramp up their attentional resources in sufficient quantities to accomplish both tasks at an equivalently high level. This ramping up of attentional resources could have resulted from the perceived increased demands of performing two tasks at the same time, which enabled the participants to track better in the dual-task easy tracking condition when listening to the mild story compared to the single-task easy tracking condition. This is in contrast to their evaluation of task demands for the single-task tracking condition, where they allocated insufficient resources to accomplish this task at the level that they did under either the mild or moderate story dual-task conditions. Consistent with the proposal is the fact that tracking performance in the single-task condition was poorer than in the dual-task condition. That is, dual-task performance generated higher levels of performance for both tasks than for either task performed alone. According to Kahneman's (1973) original formulation of resource allocation, moment-to-moment availability of attentional resources is not static and can be adjusted by motivation or perceived task demand whether drawn for exogenous or endogenous stimuli. That is, participants allocated attentional resources differently when tasks were performed in isolation compared to when they were performed in competition, and this difference could have been generated by a state of higher arousal or by utilising additional pools of resources during the dualtasks that were not available during the single tasks.

Additional support for the notion that single to dual task comparisons are specious comes from neuroimaging studies where single and dual task comparisons are made in areas of brain activation. Specifically, there are instances where performance of dual tasks recruit additional brain areas that are not active during the performance of the component tasks (e.g., Schubert & Szameitat, 2003; Szameitat, Schubert, Muller, & von Cramon, 2002) suggesting that perhaps different neural computations or processes are employed during dual-task performance that are not utilised during performance of either of the single tasks. This evidence further supports the issues of interpreting single to dual task comparisons, when it is plausible that the resources utilised for each of these tasks differ qualitatively and not merely quantitatively (Navon & Gopher, 1980).

Another alternative explanation for the unidirectional dual-task effect rests in the possibility that the index of language performance was derived, in part, from off-line processing, where participants were able to use strategies that would be unavailable during on-line comprehension or that are unavailable during the tracking tasks. Such strategies might include the opportunity to make the story retells more cohesive during the off-line retell portion of the SRP, thus increasing the efficiency of their %IUs/min. It must also be considered that the level of analysis for the SRP (the %IUS/min) may not be sufficiently fine-grained to detect a decrement in performance that can be detected with the fine-grained, pixel-level measurement used to index the tracking task.

The finding that there were no significant differences between any of the story conditions at the hard tracking level deserves comment. One possible explanation is that performance on the hard tracking condition represents a performance floor effect. That is, the tracking level was so difficult that the participants could not have performed any worse, even if they had not engaged the tracking task at all, and hence the presence of the story would not diminish their performance further, even if they had allocated much of their attention away from the tracking task and to the story task. Evidence supporting this speculation is available from the earlier study (McNeil et al., 2004) whereby the tracking error generated was similar to that derived in this condition when the cursor was held constant and no tracking was engaged.

Even with these limitations, the results do provide additional qualified support for the validity of these two dual tasks in measuring the attentional demands of persons without impairments when listening to the connected speech of persons with aphasia. This replication supports the findings from the McNeil et al. (2004) study that these dual-task stimuli and procedures provide an index of shared attention through the cost of story difficulty on tracking performance. The cost to the visual–manual tracking tasks by the language comprehension difficulty manipulation, although unidirectional, is consistent with resource allocation theory, though not exclusively so. This study was not designed to contrast theoretical accounts for any particular pattern of findings and the results are potentially consistent with bottleneck and other theoretical accounts as well.

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