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Older adults do not show enhanced benefits from multisensory information on speeded perceptual discrimination tasks

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ABSTRACT

Some research has shown that older adults benefit more from multisensory information than do young adults. However, more recent evidence has shown that the multisensory age benefit varies considerably across tasks. In the current study, older (65 – 80) and young (18 – 30) adults ($N = 191$) completed a speeded perceptual discrimination task either online or face-to-face to assess task response speed. We examined whether presenting stimuli in multiple sensory modalities (audio-visual) instead of one (audio-only or visual-only) benefits older adults more than young adults. Across all three experiments, a consistent speeding of response was found in the multisensory condition compared to the unisensory conditions for both young and older adults. Furthermore, race model analysis showed a significant multisensory benefit across a broad temporal interval. Critically, there were no significant differences between young and older adults. Taken together, these findings provide strong evidence in favour of a multisensory benefit that does not differ across age groups, contrasting with prior research.

1. Introduction

Often our environment provides sensory information in multiple domains simultaneously (e.g., visual and audio) and to successfully navigate and respond to the environment we must combine multiple sources of sensory information (e.g., looking and listening for cars when crossing the road). Given there are relationships between age-related sensory decline and age-related cognitive decline (Roberts and Allen, 2016), researchers have begun to focus on multisensory processing to tackle age deficits in cognition.

Initial reviews of multisensory processing indicated a promising message, with multisensory information reducing age-related defects (de Dieuleveult et al., 2017; Freiherr et al., 2013). For example, Peiffer et al. (2007) compared simple reaction times for detecting the onset of visual, auditory and audio-visual stimuli. They found that older adults' RTs improved more than young adults' response times for multisensory vs. unisensory stimuli. Indeed, other studies have found a larger multisensory benefit for older adults compared to young adults (Diederich et al., 2008; Hugenschmidt et al., 2009; Laurienti et al., 2006). In contrast, no age differences have been found in other speeded detection tasks (e.g., Diaconescu et al., 2013) and in some instances a greater multisensory advantage has been found in young adults (Stephen et al., 2010; Wu et al., 2012). This mixed evidence is supported by a recent review that shows age differences to be more varied on multisensory tasks with interactions arising when multisensory stimuli have attentional demands (e.g., confliction; Jones and Noppeney, 2021). Furthermore, work in our lab (Atkin et al., 2023) has consistently found no multisensory benefits at all, or similar multisensory benefits for both young and older adults. In light of these conflicting findings, we conducted a replication of a leading multisensory paradigm.

One of the most influential papers in the area of multisensory integration and aging is the seminal paper of Laurienti et al. (2006), using a speeded perceptual discrimination task. The perceptual discrimination task involved responses to the colour of a disk that is red or blue (visual colour), the words red or blue (auditory speech), or both of the above (multisensory: speech-colour disk). Reaction-time measures showed that older adults benefited more from the multisensory information than young adults (relative to slower, unisensory reaction times).

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Furthermore, race model analysis determined that the multisensory benefit was achieved over a longer temporal window for older adults compared to young adults (Laurienti et al., 2006). These findings provide evidence of a multisensory benefit for older adults over young adults. However, given the disparity in the literature, we aimed to replicate Laurienti et al. (2006) in a series of experiments with independent populations. After helpful discussions with the lead author (Laurienti), we conducted an online version (Experiment 1) of the speeded perceptual discrimination task to test if the enhanced multisensory benefit for older adults is robust when using online data collection methods (Casler et al., 2013). A face-to-face version (Experiment 2) was conducted to directly replicate the original data collection method (also to avoid potential age differences in online samples, Badham et al., 2023). Finally, a second online version was conducted that included both the colour-disks and a language condition in which the written words 'RED' and 'BLUE' replaced the colour disks (Experiment 3). The language condition provides a direct link to applied ageing research that explores benefits of adding multisensory information to written text (e.g., Stacey et al., 2023). For parsimony we report only data from the colour-disk condition below; data for the language condition can be found in the supplementary materials. In line with Laurienti et al.'s (2006) findings, we hypothesised that older adults would disproportionally benefit from multisensory information in comparison to young adults in all three colour-disk experiments.

2. Method

2.1. Transparency and openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. All data, analysis code, and research materials are available at https://osf.io/m95jx/. Data were analysed using IBM SPSS statistics, version 28 (IBM Corp, 2020) and MATLAB, (2021) was used to construct the race model analysis and figures. This study's design and its analysis were pre-registered (https://osf.io/m95jx/).

2.2. Study overview

Older (65 – 80) and young (18 – 30) adults completed a speeded perceptual discrimination task (decision on whether a red or blue stimulus is presented) either online (Experiments 1 and 3) or face-to-face (Experiment 2). The task investigated the effect of age (young, older) and presentation modality (auditory speech, visual colour, audio-visual speech-colour disk) on task response speed.

2.3. Participants

Participants for Experiments 1 and 3 samples were recruited online using Prolific and the geographical location of data collection was open to all available locations. Participants for Experiment 2 were recruited from Nottingham Trent University's participant research panels. All participants provided informed consent using the online platform Prolific. See Table 1 for participant demographics. The exclusion criteria were self-reported memory impairments/impaired cognitive function and colour blindness. All participants self-reported normal or corrected to normal vision. All participants self-reported their hearing ability to be better than or equal to fair and confirmation of clarity and ease of hearing the stimuli was obtained from all participants in a sound check during participation. During the sound check, each participant was asked to set the volume of the auditory stimuli (a single word), and participants could re-play the word as many times until the sound was clearly heard. Additional measures of self-reported everyday vision (Activities of Daily Vision scale: ADVS; Mangione et al., 1992) and hearing (Speech, Spatial and Qualities of Hearing scale: SSQ12; Noble et al., 2013) were obtained to permit correlations between perception and task performance (see Supplementary materials). Our lab previously found strong correlations (>.80) between all conditions (audio-only, visual-only, and audio-visual) using a similar response time task as the current study (Atkin et al., 2023). In order to obtain an appropriate sample, and to ensure that we at least matched the sample used by Laurienti et al. (2006), we opted for a 'moderate' correlation coefficient among repeated measures (>.50; Akoglu, 2018). An a-priori power analysis was conducted using G*power (Faul et al., 2009) to determine sample size to measure a within-between interaction using.05 (one way) significance level, small effect size (Cohen, 1988; Experiment 1 and 3 =.16, Experiment 2 =.15), and correlation among repeated measures of $r = 0.51$. The a-priori power analysis justified the sample sizes detailed in Table 1 to have an 80 % power. Each participant received a total of £5 for completing one of the 20-minute experiments. Each experiment contained independent populations. Data collection began in 2021 and ended in 2022. The study received a favourable ethics opinion from Nottingham Trent University's Research Ethics Committee.

2.4. Design and procedure

Participants completed a red/blue speeded perceptual discrimination task (Laurienti et al., 2006) (see Fig. 1). In Experiments 1 and 2, young and older adults were presented with three conditions: auditory speech, visual colour, and audio-visual speech-colour disk. Participants completed 120 trials across the 2 unisensory conditions (i.e., auditory speech, visual colour) with each of these conditions constituting 20 "Red" trials, 20 "Blue" trials and 20 "Green" trials. For the multisensory condition (i.e., audio-visual speech-colour disk), participants completed 120 trials constituting 20 "Red–Red" trials, 20 "Blue-Blue" trials, 20 "Green-Red" trials, 20 "Green-Blue" trials, 20 "Red-Green" trials and 20 "Blue-Green" trials. These conditions are direct replications of Laurienti et al (2006). The 240 trials were presented in random order. Experiment 3 was identical to Experiment 1 and 2 with the exception that there were 50 trials for each condition (auditory speech, visual colour, audio-visual speech-colour disk) with each condition containing 25 "Red" trials and 25 "Blue" trials, and no "Green" trials were presented.[1] In total 150 trials were presented to participants.

2.5. Materials and apparatus

2.5.1. Equipment

Experiment 2 (face-to-face) was run on a Lenovo ThinkCentre M79 10J7 using a 27" monitor (60-Hz refresh rate) with a 2560*1440-pixel resolution. Viewing distance was set at ~ 57 cm. The visual Sounds were presented at ~ 72 dB a SPL via two front facing speakers (Logitech X-140 S-0264B) and calibrated by presenting the stimuli over the speakers and measured using a microphone (ACO 7052E) connected to a sound level meter (SVAN 977). Experiment 1 and 3 tasks were run on various computers and monitors due to the experiments being conducted online. Sound level was set by participants so that the words could be heard clearly. The task was programmed using the web-building platform Gorilla Experiment Builder (Anwyl-Irvine et al., 2020).

2.5.2. Stimuli

For the auditory conditions, sound files ("Red", "Blue" and "Green") were recorded using Audacity 2.3.3 and normalized peak amplitude was set to −1.0 dB. The target words are spoken by a British male. For the visual conditions, the colour disks were created in Microsoft Powerpoint

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[1] Experiment 3 also contained trials where the visual stimuli were written words instead of coloured disks. These are excluded from the current analysis as they showed similar response patterns and add little theoretical insight to the current narrative. Please see supplementary material for complete analysis of all Experiment 3 conditions.

Table 1
Participant demographics (age and education) and descriptive statistics for education, SSQ12, ADVS and results of t tests with effect sizes.

	Young		Older				
	M(SD)	*N*	M(SD)	*N*	Group difference		
Experiment 1					*t*	*p*	*d*
Age	23.74 (3.78)	31 (f =23)	69.06 (3.21)	31 (f =14)			
Education	2.77 (1.02)	31	2.63 (1.22)	30	< 1	=.626	.12
SSQ12	7.50 (1.44)	31	7.30 (1.38)	31	< 1	=.591	.14
ADVS	4.84 (.17)	31	4.66 (.25)	31	3.35	=.001	.85
Experiment 2							
Age	24.60 (3.16)	36 (f =23)	71.83 (4.37)	36 (f =19)			
Education	3.34 (.84)	36	3.14 (1.05)	36	< 1	=.369	.22
SSQ12	6.72 (1.38)	36	7.50 (1.60)	36	−2.19	=.016	.52
ADVS	4.68 (.31)	36	4.57 (.24)	36	< 1	=.082	.42
Experiment 3							
Age	24.9 (3.92)	31 (f = 23)	70.0 (3.76)	31 (f =22)			
Education	2.71 (.90)	31	2.39 (.92)	31	1.40	=.080	.35
SSQ12	7.80 (1.26)	31	7.23 (1.74)	31	1.48	=.073	.36
ADVS	4.82 (.16)	31	4.65 (.28)	31	3.02	=.004	.25

Note. f = number of females in the sample. The distribution of sex only differed between young and older adults in Experiment 1 ($x^2(1) = 6.00$, p =.014). Education = level of education (secondary schooling U.K. – doctoral degree), SSQ12 (Noble et al., 2013) and ADVS (Mangione et al., 1992). Level of education was scored on a scale of 1 – 5 (1 = secondary schooling U.K, 2 = A-levels or equivalent, 3 = bachelor's degree or equivalent, 4 = master's degree or equivalent, 5 = PhD or equivalent), a higher score on the 12-item SSQ12 questionnaire indicates better auditory functioning, the ADVS scale measures visual functioning in different situations and consists of 21-multiple choice questions which are rated on a scale from 1 to 5. A higher score on this questionnaire indicates better visual functioning. p = two-tailed test.

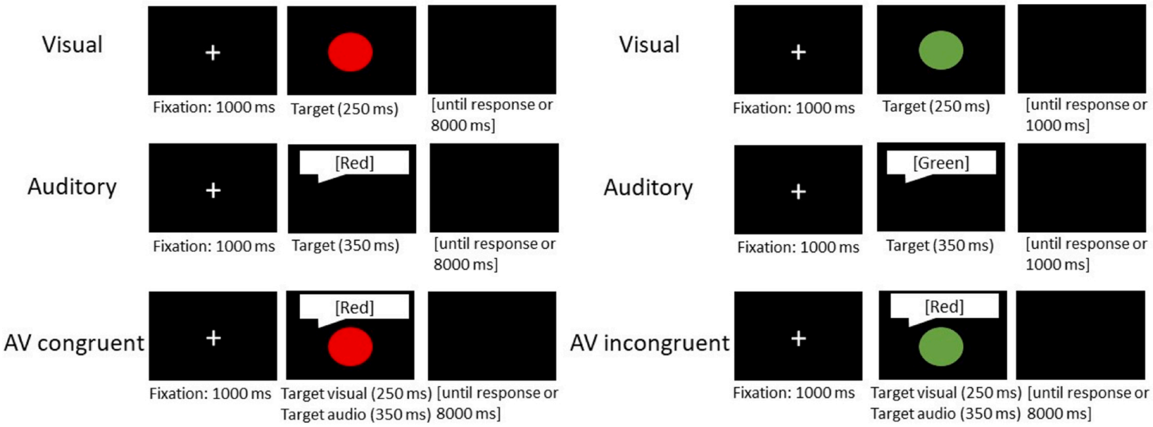

Fig. 1. Each trial began with a white fixation cross, presented at the centre of the display on a black background. After which, the test stimulus was presented. Trials that contained visual information were presented at the center of the screen and auditory information was presented with the screen remaining blank. On audio-visual trials, visual and auditory onsets were simultaneous. After the presentation of the test stimulus a black screen was presented. Participants responded using the keyboard by pressing the 'F' and 'J' key whenever blue or red was presented in a trial and were told to ignore the colour green. If a response was made, then the next trial began. However, if a response was not made, then the program continued onto the next trial. At the beginning of the task participants were instructed to respond as quickly as possible while maintaining accuracy. The design and procedure are identical to Laurienti et al. (2006). Experiment 3 was identical to Experiment 1 and 2 with the exception that no green trials were presented.

and measured 283.5 pixels (Experiment 2: visual angle of diameter ~ 5°). The shape format of the disks were circles filled with the colour red (RGB: 255, 0, 0), blue (RGB: 0, 176, 240) or green (RGB: 146, 208, 80) and were presented at the center [X, Y (0, 0)] of a black (RGB: 0, 0, 0) screen. Audio-visual conditions combined both the auditory and visual stimuli with simultaneous onsets. Experiment 2

3. Results

3.1. Data preparation

Response-time data were trimmed to exclude responses that were too fast (<100 ms) or too slow (>4000 ms). Trimming resulted in the removal of 0.68 % of trials. Incorrect trials were not eliminated from analysis (Laurienti et al., 2006). Incorrect trials accounted for 2.96 % of the data across the three experiments (Experiment 1 = 3.10 %, Experiment 2 = 2.16 %, Experiment 3 = 3.65 %). Three participants were removed from Experiment 3 and one participant was removed from Experiment 1 and 2, due to either poor performance (< 60 % accuracy) or confusing the response keys 'F' and 'J'. In accordance with Laurienti et al. (2006), all "green" trials were removed from analysis.

3.2. Statistical analysis

Data from each experiment were analysed in accordance with the respective pre-registrations (see supplementary material). The main dependent variable was log RT (higher values indicate slower responses) as this accounts for general aged-related slowing (c.f., Verhaeghen, 2011). Raw RTs and mean accuracy scores were also analysed but are not of primary interest (Laurienti et al., 2006). A 2 (age: young, older adults) x 3 (modality: auditory speech, visual colour, audio-visual speech-colour disk) mixed ANOVA was conducted on log reaction times for each experiment (Table 3). In addition, the data from all experiments were collapsed into one model: a 2 (age: young, older adults) x 3 (Experiment: 1, 2, 3) x 3 (modality: auditory speech, visual colour, audio-visual speech-colour disk) mixed ANOVA on log reaction times

(Table 3). Laurirenti et al's. (2006) race model analysis was used to analyse RTs using cumulative distribution functions (CDFs). For details of the race model, see Miller (1982), (1986) and supplementary materials for race model procedure. Bayes factors (BF$_{10}$) were calculated using JASP software (Love et al., 2015) as a measure of evidence for the null/alternative hypotheses (see Jarosz and Wiley, 2014) for ANOVAs and race model analysis. The Bayes factor provide an odds ratio for the hypotheses (values $<$1 favours the null hypothesis and values $>$1 favour the alternative hypothesis). Previous evidence has associated labels with the respective strength of the bayes factors, with labels such as "substantial", "strong", and "decisive" indicating factors of 3, 10, and 100, respectively (Wetzels et al., 2011). We report BF$_{\text{inclusion}}$ for each effect.

The means and standard errors for log RTs for each experiment (1, 2 and 3) and collapsed data (experiment 1 – 3) can be seen in Table 2, with a summary of ANOVA results in Table 3. The means and standard errors for mean RTs for and collapsed data (experiment 1 – 3) can be seen in Fig. 2. Descriptive and inferential statistics for mean RTs and accuracy can be found in the supplementary materials. As expected, there was a significant effect of age with young adults responding faster than older adults. There was a significant effect of modality, with both groups responding faster when information was presented audio-visually compared to visually or auditorily. These main effects were observed across all experiments. There was an interaction between age group and modality in Experiments 1 and 2, showing that audio information was responded to similarly by both young and older adults, whilst conditions involving visual and audiovisual stimuli were responded to faster by young adults than by older adults. Hence, while there was an interaction between age group and modality, it did not show an increased multisensory benefit (audio or visual vs audio-visual) for older adults compared with young adults. There was a significant interaction between modality and experiment, showing that responses were faster in Experiment 3 than Experiment 1 and 2 for audio, visual and audio-visual, whereas there was no significant differences between Experiment 1 and 2 for audio, visual and audio-visual.

A race model analysis conducted on data collapsed across all three experiments revealed a significant speeding of response in the multisensory condition compared to the visual only and audio only conditions (Fig. 3a), for both young (Fig. 3b) and older adults (Fig. 3c). Furthermore, the multisensory benefit was greater than that predicted by the race model (Fig. 3d) with this benefit being statistically significant (p's $<$. 001 - $<$.017, d =.15 –.42) across a broad temporal interval (320-ms – 630-ms) and its peak resulted in a multisensory enhancement of 4.4 % at 550-ms. Bayesian analysis across the temporal interval (320-ms – 630-ms) indicated decisive support for the alternative hypotheses (BF$_{10}$ = 4.04 x 10^{87}, i.e., multisensory benefit was greater than that predicted by the combined effect of the unisensory information). Critically, there were no significant differences between the probability difference of the young and older adults across the temporal interval, indicating strong evidence in favour of the null hypothesis (BF$_{10}$ =.101, i.e., no multisensory difference between young and older adults). The magnitude of this result held when accounting for potential age differences in speed of response.[2] Peak performance was similar between the two groups: young adults' performance resulted in a 4.9 % benefit at 530-ms, whereas older adults' performance resulted in a 4.8 % benefit at 550-ms (Fig. 3d). Taken together, findings provide decisive evidence in favour of a comparable multisensory benefit for both young and older adults. Race model analysis for each individual experiment is also provided (see supplementary materials for details). Given that Experiment 3 used a different paradigm compared to Experiment 1 and 2, the data of Experiment 1 and Experiment 2 has been collapsed into one race model and shows a multisensory benefit across a broad temporal interval, and crucially, no multisensory difference between young and older adults were found when accounting for age-related latency differences (see supplementary materials).

Table 2

Log response times (RT) with standard errors for unisensory (auditory and visual) and multisensory conditions for each experiment (1, 2 and 3).

	Auditory	Visual	Multisensory
Experiment 1			
Older adults RT	2.84 (.02)	2.75 (.01)	2.74 (.01)
Young adults RT	2.80 (.02)	2.70 (.01)	2.67 (.01)
Experiment 2			
Older adults RT	2.89 (.02)	2.82 (.02)	2.79 (.01)
Young adults RT	2.87 (.02)	2.77 (.02)	2.73 (.01)
Experiment 3			
Older adults RT	2.91 (.02)	2.86 (.02)	2.80 (.02)
Young adults RT	2.87 (.02)	2.80 (.01)	2.74 (.02)
All experiments			
Older adults RT	2.88 (.01)	2.81 (.01)	2.78 (.01)
Young adults RT	2.85 (.01)	2.75 (.01)	2.71 (.01)

4. Discussion

The study was designed to establish if presenting stimuli in multiple sensory modalities (audio-visual) instead of one (audio-only or visual-only) provided greater benefits to older adults compared to young adults. We used a speeded perceptual discrimination task (decision on whether a red or blue stimulus is presented) to assess RTs, either online (Experiments 1 and 3) or face-to-face (Experiment 2). Across all three experiments, young adults produced faster RTs than older adults, and a consistent speeding of response was found in the multisensory condition compared to the unisensory conditions for both young and older adults. Race model analysis showed that the multisensory benefit was greater than would be expected if the unisensory inputs were combined additively with a significant benefit across a broad temporal interval, and peak multisensory enhancement of 4.4 %. Critically, there were no significant differences between the probability differences of the young and older adults, with Bayes analysis providing decisive evidence favouring the null result. Overall, the data presented here demonstrate that both young and older adults benefit similarly from multisensory information with these findings being incongruent with those of earlier studies (e.g., Laurienti et al., 2006), which consistently found a disproportionate multisensory benefit in all response time measures for older adults.

The lack of enhanced multisensory benefit for older adults over young adults found in the current study conflicts with previous evidence which used speeded perceptual discrimination tasks (e.g., Laurienti et al., 2006; Peiffer et al., 2007). One potential explanation for this difference is that many of the papers that report a multisensory benefit for older adults were conducted pre-2010 (Diederich et al., 2008; Hugenschmidt et al., 2009; Laurienti et al., 2006). Older adults today are more cognitively able than those of the previous generations (Badham, 2024) and have more experience with technology (Laricchia, 2022). Both these factors could influence age differences in responses to audio-visual stimuli within computer-based tasks. However, the current study did not measure if the population samples had greater exposure to multisensory technology (e.g., computer-based tasks) over the last decade. Further research should include a measure of comfort and experience in using multisensory technology to help substantiate this explanation.

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[2] To account for general age-related latency differences (see Figure 3 Panel d), Bayesian analysis was calculated comparing all time bins where the multisensory benefit was greater than 0 for young adults (200–250 ms, 290–660 ms) to all time bins that were greater than 0 for older adults (260–760 ms) and collapsed into one dependent variable for each age group. The Bayesian analysis indicated decisive support for the null hypothesis, BF$_{10}$ =.037 (i.e., no multisensory difference between young and older adults). Additionally, for each individual 10 ms time bin, there was no significant difference between the young and older adults across the main temporal interval (320-ms – 630-ms, mean BF$_{10}$ =.432 except for 610-ms - 620-ms, BF$_{10}$ = 2.18).

Table 3
Summary of ANOVA effects for Experiment 1, 2 and 3 on log response time.

	F	DF	*p*	η_p^2	*BF₁₀*	Post-Hoc Tests
Experiment 1						
Modality	215.12	2118	<.001	.77	$1.334x10^{14}$	MS < V & A, V < A
Age	4.67	1,59	.035	.07	32.96	Young < Older
Modality*Age	7.19	2120	=.001	.11	67.05	Age comparisons$A_{young} = A_{older}$, $V_{young} < V_{older}$, $MS_{young} < MS_{older}$Older Adult Comparisons$A_{older} > V_{older}$ & MS_{older}, $MS_{older} < V_{older}$Young Adult Comparisons$A_{young} > V_{young}$ & MS_{young}, $MS_{young} < V_{young}$
Experiment 2						
Modality	190.54	2138	<.001	.73	∞	MS < V & A, V < A
Age	7.25	1,69	.009	.10	5.86	Young < Older
Modality*Age	3.01	2138	.052	.04	2.83	Age comparisons$A_{young} = A_{older}$, $V_{young} < V_{older}$, $MS_{young} < MS_{older}$ Older Adult Comparisons$A_{older} > V_{older}$ & MS_{older}, $MS_{older} < V_{older}$Young Adult Comparisons$A_{young} > V_{young}$ & MS_{young}, $MS_{young} < V_{young}$
Experiment 3						
Modality	134.94	2114	<.001	.70	$2.224x10^{14}$	MS < V & A, V < A
Age	7.14	1,57	.010	.11	4.33	Young < Older
Modality*Age	1.49	2114	.229	.03	1.21	
All Experiments						
Modality	518.07	1.74,3.48	<.001	.74	∞	MS < V & A, V < A
Age	18.44	1,85	<.001	.09	46801.74	Young < Older
Experiment	17.80	2185	<.001	.16	$3.431x10^{6}$	Exp 1 = Exp 2, Exp 3 < Exp 1 & Exp 2
Modality*Age	9.05	2370	.052	.05	269.69	Age comparisons$A_{young} < A_{older}$, $V_{young} < V_{older}$, $MS_{young} < MS_{older}$ Older Adult Comparisons$A_{older} > V_{older}$ & MS_{older}, $MS_{older} < V_{older}$, Young Adult Comparisons$A_{young} > V_{young}$ & MS_{young}, $MS_{young} < V_{young}$
Modality * Experiment	5.36	4370	<.001	.06	108.17	A_{exp3}, < A_{exp1} & A_{exp2}, $V_{exp1} < V_{exp3}$ & V_{exp2}, $MS_{exp3} < MS_{exp1}$ & MS_{exp2}, $A_{exp1} = A_{exp2}$, $V_{exp1} = V_{exp2}$, $MS_{exp1} = MS_{exp2}$In each experiment: MS < V & A, V < A.
Experiment * Age	< 1				.54	
Modality * Age * Experiment	< 1				.19	

Notes. A = Audio, V = Visual, MS = Multisensory. < faster response time, > slower response time, = is approximately equal to.

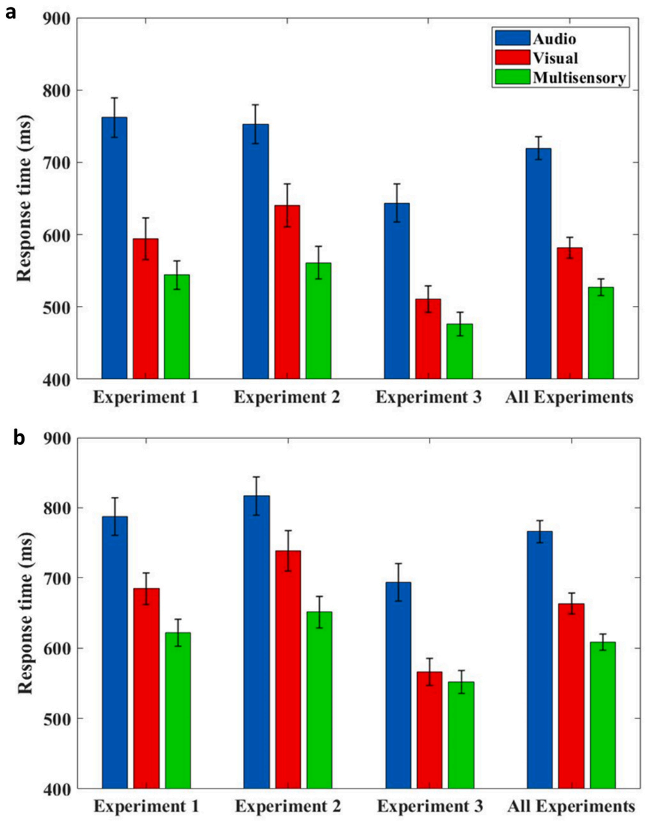

Fig. 2. Young (a) and older (b) participants mean response time (milliseconds) for unisensory (audio, visual) and multisensory (audio and visual) information across each experiment (1, 2, 3 and all experiments). Error bars indicate standard errors.

The similar multisensory benefit across age is aligned with the findings of a recent review on aging and multisensory integration (Jones and Noppeney, 2021), which argued that multisensory age differences are more complicated than suggested in earlier reviews (e.g., de Dieuleveult et al., 2017; Freiherr et al., 2013). Furthermore, Atkin et al. (2023) found a similar multisensory benefit for lexical decision accuracy and memory performance for both young and older adults. Additionally, a multisensory response time *disadvantage* was found for both age groups during lexical decisions, relative to a visual-only condition. Taken together, these findings suggest that the type of task (e.g., simple reaction time task vs tasks requiring higher-order cognitive demands) and stimuli (e.g., simple coloured stimuli vs words requiring lexical access) are influencing factors in effective multisensory processing.

Experiments 1 and 2 directly replicated the design of studies by Laurienti et al. (2006), which included incongruent trials, and the speeding of responses in the multisensory condition over unisensory conditions still held for both young and older adults. These are important findings given that incongruency has been highlighted as a factor influencing age differences in multisensory integration aging studies (Jones and Noppeney, 2021) and global task switching (e.g., switching between congruent and incongruent trials) performance is reduced in older adults (Verhaeghen, 2011). Given this evidence it would be expected that older adults would be slowed by the presence of incongruent stimuli to a greater extent than young adults. Rather, the overall results of the current study demonstrate that both young and older adults receive a similar benefit from multisensory information, independent of whether the task involves global task switching.

Interestingly, it was found that age deficits were smaller for auditory-only trials compared with visual-only or multisensory trials. A recent meta-analysis which separated out accumulation of information in response-time tasks (accounting for encoding and motor-response differences) found that older adults can accumulate information for lexical decisions faster than young adults (Theisen et al., 2021). It may be the case that older adults can leverage intact vocabulary skills (Verhaeghen, 2003) to complete language-based cognitive tasks, while still showing typical age-related slowing in accumulation of perceptual information

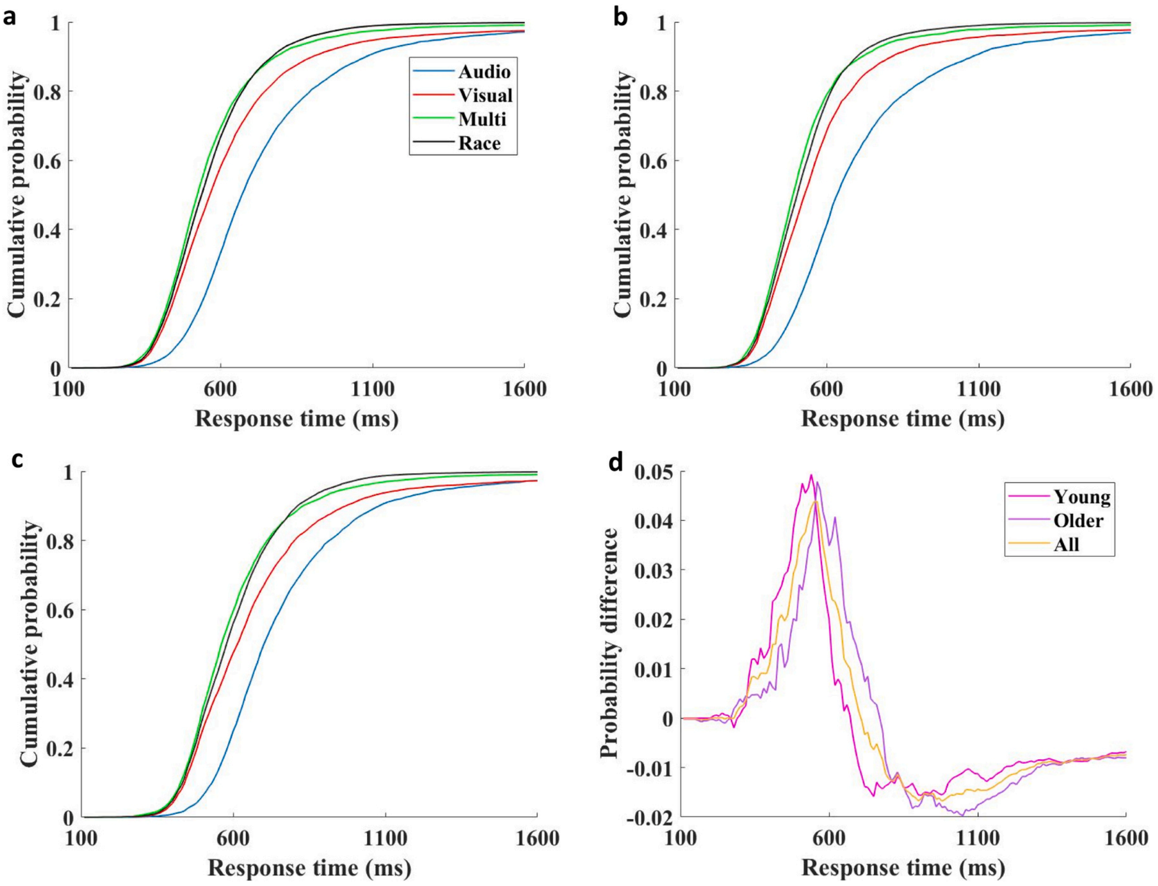

Fig. 3. Cumulative distribution functions (CDFs) for log response times on auditory (blue curve), visual (red curve) and multisensory (green curve) conditions, and the race model (black curve). (a) CDFs for all participants. (b) CDFs for young adults. (c) CDFs for older adults. (d) The cumulative difference benefit under the multisensory condition compared to the race model prediction for all participants (yellow), young adults (pink) and older adults (purple).

(Theisen et al., 2021). It may also be the case that participants waited until the end of the audio recording before responding, allowing older adults to catch up to young adults. However, all participants were instructed to respond as quickly and as accurately as possible.

The information degradation hypothesis (Monge and Madden, 2016; Pichora-Fuller and Singh, 2006) suggests that when perceptual information is degraded, the additional processing demands and impoverished representations lead to impaired cognitive performance. Support for the information degradation hypothesis comes from studies with both young and older adults that show that degrading the perceptual input has a negative impact on cognitive processes such as visual search, memory, face processing, and digit-symbol substitution (e.g., Bertone et al., 2007; Billig et al., 2020; Boutet and Meinhardt-Injac, 2019; Dickinson and Rabbitt, 1991; Gilmore et al., 2006; Laudate et al., 2012; Toner et al., 2012, as well as the present study). The information degradation hypothesis would further predict that differences in the clarity of perceptual information will have greater impact on older adults than young adults, due to age-related slowing and reduced ability to compensate for reductions in perceptual clarity. This aspect of the information degradation hypothesis was supported by Laurienti et al.'s (2006) original findings, but is contradicted by the current study. In the wider research literature, evidence for an interaction between age and perceptual clarity has been mixed. While some studies show an interaction between age and perceptual clarity (Allen et al., 2017; Boutet and Meinhardt-Injac, 2019; Cronin-Golomb et al., 2007; Laurienti et al., 2006), others show no additional costs/benefits for older adults relative to young adults (Billig et al., 2020; Laudate et al., 2012; Toner et al., 2012; present study). Findings appear to be sensitive to the specific cognitive process, task design, and task difficulty (Monge and Madden, 2016) and also to the salience and/or valence of the stimuli (e.g., Allen et al., 2017). The mixed findings could also indicate that the predicted interaction fails to take into account other relevant factors, such as older adults' increased motivation to do well in cognitive studies and greater experience managing degraded perceptual input. While older adults may have less *capacity* to compensate for reduced perceptual clarity, they may make greater use of their existing capacity than young adults, resulting in equivalent multisensory costs/benefits.

Since Experiments 1 and 3 were conducted online, it's probable that the RGB colours differed across participants and monitors due to the absence of monitor calibration (i.e., using standard gamma settings to balance true colours). Potentially, this resulted in different levels of colour clarity for individual participants in the online studies. The red and blue colours in our study should be relatively robust to minor differences across monitors, and we found no differences across the online and lab-based studies. However, research with more subtle colour differences should aim to ask participants to individually adjust gamma settings in order to optimise visibility of stimuli.

While the present study has focused on responses to multisensory signals, the benefit found for both young and older adults does not necessarily reflect multisensory integration, but could instead reflect co-activation (Miller, 1982). Similar processing benefits have been found when two redundant visual stimuli are presented in a single location with older adults demonstrating an enhanced benefit compared to young adults (Bucur et al., 2005). Future research should aim to investigate if today's generation of older adults would similarly show this enhanced benefit.

In conclusion, the present findings show that young and older adults can similarly benefit from multisensory processing. These findings are in conflict with one of the most influential papers in the area of multisensory integration and aging (Laurienti et al., 2006), and may reflect cohort changes over time, including older adults' ability to perform computer-based tasks. Our findings demonstrate that the use of multiple sensory channels improves cognitive processing similarly for both young and older adults.

Verification

The article is not under consideration for publication elsewhere and the final article has been approved by all authors.

Authors note

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CRediT authorship contribution statement

Christopher Atkin: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jemaine E Stacey:** Writing – review & editing, Methodology, Conceptualization. **Harriet A Allen:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition. **Helen Henshaw:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition. **Roberts L Katherine:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition. **Stephen P Badham:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation.

Conflict of Interest

The authors declare no competing interests.

Data Availability

The data of the current study are available in the Open Science Framework repository, http://osf.io/m95jx/.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neurobiolaging.2024.08.003.

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