ORGANISING BY OBJECT : HOW AUDITORY MEMORY CAN BE STRUCTURED WITHIN COMPLEX SCENES

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1. INTRODUCTION

Objects are considered important units of short-term memory in vision [1,2]. This experimental series was an attempt to detail the extent to which analogous memorial organisation can take place in audition. The initial design was based on [1] in which participants were presented with two objects differing along two separate attributes (i.e., line: orientation and texture; box: size and gap location). Participants were better at remembering two attributes when they were derived from the same object (e.g., orientation and texture) relative to retrieving two attributes derived from different objects (e.g., orientation and size).

1. METHOD

2.1 Stimuli

Variations in two 500 ms sounds (tone and noise) were created, with each sound having a 10 ms linear onset and offset. Noise was low-pass filtered to sound like *wind* (+20 dB under 510 Hz, 0 dB 510-1200 Hz, -20 dB over 1200 Hz) or high-pass filtered to sound like *rain* (-20 dB under 510 Hz, 0 dB 510-1200 Hz, +20 dB over 1200 Hz). Amplitudes for both types of noise were then increased or decreased linearly in intensity to give the impression of moving *towards* or *away* from the listener. The tone was either *high* (1122 Hz) or *low* (750 Hz) in pitch and was frequency modulated (modulation frequency: 5 Hz, deviation frequency: 10%) or not to give the *presence* or *absence* of a warble. All variations of tone and noise were mixed and calibrated binaurally at 70 dB SPL(A) using Sennhesier HD580 headphones, and a Brüel & Kjœr sound level meter (Type 2610) and artificial ear (Type 4153).

2.2 Design and procedure

At each trial, participants were presented with a blank screen for 1000 ms and then two cue dots for 1500 ms, after which the combined noise/tone was played. Two of four possible prompts followed. Each prompt presented a to-be-remembered attribute centre screen with the two possible values of the attribute left and right of centre: 'Wind [CLIMATE] Rain' and 'Towards [DIRECTION] Away' for the noise, 'Low [PITCH] High' and 'No [WARBLE] Yes' for the tone. For both prompts, participants pressed a left or right button in accordance with their memory of the acoustic attribute. All possible combinations of tone and noise were presented equally and each attribute was interrogated equally across same- and different-object responses, and across first and second prompts. All experimental analyses were based around repeated-measures ANOVAs with the factors of object (same, different) and response (first, second). Since the distinction between same and different object was essentially meaningless during the first response, RT advantages and/or error rate reductions for same-object responding relative to different-object responding were expected only for the second response in a pair.

2. RESULTS

3.1 Experiment 1

Experiment 1 set out to establish the basic effect in that participants should be better at retrieving multiple attributes when they originate from the same auditory object relative to different auditory objects. Table 1 supports the critical object x response interaction ($F[1,10] = 6.03$, $p = .034$), with Tukey's HSD test ($p < .05$) revealing faster RTs for the second response in a pair when the to-be-remembered attribute was derived from the same object as the first (see [3] for further details).

Table 1. Summary statistics for Experiment 1

	RT (ms)	RTSE (ms)	Error (%)
1st Response Same	1273	93	12.89
1st Response Diff	1276	95	13.14
2nd Response Same	992	57	14.28
2nd Response Diff	1091	40	14.80

3.2 Experiment 2

The flexibility of object-based organisation was tested in Experiment 2 via the use of a cue [4]. If such organisation was purely strategic, then it should be possible to abolish the effect by alerting participants to the fact that they will have to retrieve information from different objects prior to acoustic stimulation. For half of the same-object trials and half of the different-object trials, participants were cued to the attributes they would have to respond to. The ANOVA revealed an average benefit of over 200 ms for cueing ($F[1,17] = 45.86$, $p < .001$). However, the effect of cue failed to modulate the object x response interaction ($F[1,17] = 4.86$, $p =.041$; see Table 2). Tukey's HSD test ($p < .05$) confirmed the same-object advantage for the second response in a pair for both cued and uncued conditions.

Table 2. Summary statistics for Experiment 2

UNCUED	RT (ms)	SE (ms)	Error (%)
1st Response Same	1526	71	11.11
1st Response Diff	1526	77	12.58
2nd Response Same	1264	47	14.84
2nd Response Diff	1292	56	15.45

CUED	RT (ms)	SE (ms)	Error (%)
1st Response Same	1306	80	9.38
1st Response Diff	1296	65	12.93
2nd Response Same	996	77	14.59
2nd Response Diff	1073	73	12.41

3.3 Experiment 3

Object-based organisation is often put into competition with other forms of organisation such as space [2] when assessing memorial structure. Experiment 3 was identical to the uncued condition of Experiment 2, save for that stimuli were now presented monaurally and for half of the same- and different-object trials, sounds were presented to the same or different ear. If space and object make additive contributions to the organisation of auditory memory, then the benefit accrued for same-object responding should be larger during different ear conditions. As shown in Table 3, ear of delivery failed to impact upon the standard object x response interaction ($F[1,17] = 4.97$, $p = .039$), with Tukey's HSD test ($p < .05$) in which the same-object advantage was revealed for the second response in a pair. The data are consistent with the idea that space works as a useful organisational factor in auditory scene analysis only when other grouping mechanisms are ambiguous [5].

Table 3. Summary statistics for Experiment 3

SAME EAR	RT (ms)	SE (ms)	Error (%)
1st Response Same	1260	77	12.15
1st Response Diff	1288	77	11.20
2nd Response Same	1005	45	14.93
2nd Response Diff	1122	44	14.14

DIFFERENT EAR	RT (ms)	SE (ms)	Error (%)
1st Response Same	1265	74	10.76
1st Response Diff	1245	54	12.24
2nd Response Same	1036	45	15.71
2nd Response Diff	1113	47	15.53

3.4 Experiment 4

By introducing time lags into the paradigm, it should be possible to assess the temporal limits of auditory object-based organisation. Time lags of 0ms or 2000ms were introduced inbetween the end of the sound and start of the first prompt, and/or, the end of the first feedback and start of the second prompt (appearing as *x–y* Lag in Table 4). Here, the standard object x response interaction was subsumed by a further interaction with the second kind of time lag ($F[1,17] = 14.88$, $p = .001$). Tukey's HSD test ($p < .05$) revealed that the same-object advantage was abolished with long delays inbetween first and second prompt. As shown in Table 4, the data are consistent with the characterisation of object-based organisation in terms of mutual interference during different-object trials rather than mutual facilitation during same-object trials [1], in that different-object trials show significant speeding as time lag increases.

Table 4. Summary statistics for Experiment 4

0–0 LAG	RT (ms)	SE (ms)	Error (%)
1st Response Same	1320	68	11.11
1st Response Diff	1309	67	11.46
2nd Response Same	1089	78	11.46
2nd Response Diff	1169	68	9.90

0–2000 LAG	RT (ms)	SE (ms)	Error (%)
1st Response Same	1287	57	10.42
1st Response Diff	1288	72	13.37
2nd Response Same	1112	74	13.37
2nd Response Diff	1077	58	13.19

2000–0 LAG	RT (ms)	SE (ms)	Error (%)
1st Response Same	1085	53	10.24
1st Response Diff	1092	54	11.63
2nd Response Same	1001	76	11.63
2nd Response Diff	1156	56	10.76

2000–2000 LAG	RT (ms)	SE (ms)	Error (%)
1st Response Same	1123	59	14.58
1st Response Diff	1120	67	14.93
2nd Response Same	1027	68	13.37
2nd Response Diff	1062	53	14.93

3.5 Experiment 5

Experiment 5 refuted an alternative explanation of the data based on different attribute association strengths between conditions. In previous experiments, an attribute (i.e., PITCH) predicted only one same-object attribute (i.e., WARBLE) but two different-object attributes (i.e., DIRECTION or CLIMATE). However, an object x response interaction was revealed ($F[1,27] = 4.50$, $p = .043$) when the first attribute equally predicted its sibling attribute or only one of the attributes from the other object (see Table 5).

Table 5. Summary statistics for Experiment 5

	RT (ms)	SE (ms)	Error (%)
1st Response Same	1449	69	9.82
1st Response Diff	1483	77	10.38
2nd Response Same	1169	50	13.76
2nd Response Diff	1272	50	13.00

3. DISCUSSION

The data across Experiments 1-5 support the case for object-based organisation in auditory memory. This kind of organisation appears to be exogenous (Experiments 1 and 2), does not interact with spatial organisation (Experiment 3) but is sensitive to temporal delay (Experiment 4). Despite initial transduction difference between the senses, there is an extent to which the phenomenology of everyday life is represented in a rich, multi-modal code. These current observations suggest that associated features (i.e., objects) serve as important cognitive representations for both visual and auditory stimuli [6, 7] and that as a shared representational code, objects may be a useful construct in thinking about how disparate sensory information is eventually bound together. Indeed, a recent revision of one influential model of memory posits additional mechanisms that attempt to account for exactly these kinds of concern (e.g., episodic buffer; [8]). Further research examining the same-object advantage using multi-modal stimuli should reveal additional insights into how we organise the collection of not only sounds, but also sights and sensations that define our previous experiences.

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