Implicit estimation of sound-arrival time

In perceiving the sound produced by the movement of a visible object, the brain coordinates the auditory and visual input so that no delay is noticed even though the sound arrives later (for distant source objects, such as aircraft or firework displays, this is less effective). Here we show that coordination occurs because the brain uses information about distance that is supplied by the visual system to calibrate simultaneity. Our findings indicate that auditory and visual inputs are coordinated not because the brain has a wide temporal window for auditory integration, as was previously thought, but because the brain actively changes the temporal location of the window depending on the distance of the visible sound source.

Seven subjects with normal vision and hearing were presented through headphones with a burst of white noise (90 decibels sound-pressure level, 10-ms duration, with 4-ms rise and fall times), the spectrum of which had been processed (by using head-related transfer functions) to simulate an external sound from a frontal direction. Brief light flashes (10 ms) were produced by an array of five green light-emitting diodes (LEDs) at different distances from the subjects (1–50 m; Fig. 1). The intensity of the light flash was 14.5 candelas per square metre at a viewing distance of 1 m, and was increased in proportion to the square of the viewing distance for the other distances in order to produce consistent intensity at the eye. The difference in onset times between the sound and light stimuli was varied randomly from −125 ms to 175 ms in steps of 25 ms.

Subjects were instructed to look at the centre of the LED array and to imagine that the LEDs were the source of both light and sound, while listening to the sound directly from the sound source. To eliminate possible bias effects, we used a two-alternative forced-choice task to measure subjective simultaneity: in this task, observers judged whether the light was presented before or after the sound.

Twenty responses were obtained for each condition. To determine the stimulus-onset asynchrony that corresponded to subjective simultaneity, we estimated the 50% point (the point of subjective equality) by fitting a cumulative normal-distribution function to each individual’s data using a maximum-likelihood curve-fitting technique.

When the LED array was 1 m away, the point of subjective equality occurred at a sound delay of about 5 ms; however, the sound delay at this point increased with viewing distance (P < 0.001; Fig. 1a, b). This increased delay was roughly consistent with the velocity of sound (about 1 m per 3 ms at sea level and room temperature), so the point of subjective equality increased by about 3 ms with each 1-m increase in distance. This relationship was consistent at least up to a distance of 10 m.

Our results show that the brain probably takes sound velocity into account when judging simultaneity. However, it takes about 120 ms for sound to travel 40 m, and we found that the threshold for detecting the sound delay was 106 ms at a viewing distance of 40 m, so active compensation is likely to operate only for shorter distances than this.

We have shown that the brain takes sound velocity into account when integrating audiovisual information. The brain can therefore integrate audiovisual information over a wide range of temporal gaps, and correctly match sound and visual sources.

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Figure 1  Synchrony in audiovisual perception. a, Representative results from one observer. The percentage of light-first response for each viewing distance is plotted against sound delay (stimulus-onset asynchrony). Different colours represent results for different viewing distances (red, pink, yellow, green, blue, brown and black correspond to 1, 5, 10, 20, 30, 40 and 50 m, respectively). Dashed line indicates the 50% point, which corresponds to subjective simultaneity. b, Points of subjective equality (filled circles) plotted against viewing distance. Hollow circles, plots of 25% (bottom curve) and 75% (top) of light-first response indicate the threshold for detecting asynchrony. Dashed line represents the real sound-arrival time.
brief communications

building and religion have been crucial alternatives over our long evolutionary history, with a legacy that pervades today. Dominic D. P. Johnson*, Pavel Stopka, Stephen Knights

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Fehr and Gächter reply — The claim by Johnson et al. that human cooperation in social-dilemma games violates rational-choice theory is not justified1. If people have altruistic aims, altruistic behaviour is a rational means by which to achieve their proximate goals. From an evolutionary viewpoint, we need to explain why humans are often altruistic by strong reciprocity2. Although kin selection, reciprocal altruism, and indirect reciprocity explain relevant forms of human cooperation3,5,7, they do not usually explain strong reciprocity9.

Kin selection would account for strong reciprocity if human behaviour were driven by rules that do not distinguish between kin and non-kin. But humans, like other primates, distinguish cognitively and behaviourally between the two3,9, and generally feel stronger emotions towards kin. Likewise, reciprocal altruism could account for strong reciprocity if humans’ behavioural rules did not depend on the probability of future interactions with potential opponents. But humans can distinguish long-term partners from people with whom future interaction will be less likely (‘strangers’), and will cooperate more if they anticipate that interaction will be frequent7. Emotional responses may also be stronger towards a long-term partner than towards a ‘stranger’ (our unpublished results).

Reputation-based ultimate theories could account for strong reciprocity if our behavioural rules did not depend on our actions being observed by others. However, if reputation formation is ruled out, cooperation breaks down, whereas it flourishes if subjects gain in reputation7.

Early humans whose behaviour was fine-tuned to respond to kin or non-kin, partners or strangers, and gaining in reputation, probably had an evolutionary advantage because, contrary to common belief, they faced interactions where the probability of future encounters was sufficiently low as to make defection worthwhile. Ethnographic evidence indicates that humans had many encounters with individuals with whom they had little future interaction6. In addition, the costs of mistakenly treating unrelated individuals as kin, or treating strangers as partners, were high — for instance, a lack of vigilance with strangers could be fatal. Because of these costs, individuals who could adjust their behaviour to suit their opponent’s characteristics had greater fitness.

The problem with any theory claiming that strong reciprocity is maladaptive in modern circumstances is that individuals understand the risks of exploitation in interactions with non-kin and strangers, and behave accordingly. An evolutionary explanation of strong reciprocity is needed that does not assume that individuals are maladapted10.

A proximate mechanism of belief in supernatural punishment does not solve the evolutionary puzzle. How could such beliefs evolve if those who did not hold them defected and hence gained an advantage? Laboratory experiments do not support the claim that religion is important for cooperation. If other people in the group are expected to defect, then almost everyone else — religious or not — will defect too10. Moreover, in almost all religions, non-believers have been ostracized and have faced worldly punishment.

We do not agree that anonymity is a problem in the experiment: it rules out other, less costly forms of social punishment that are available in non-anonymous situations, such as workers’ hostility towards strike-breakers and people’s hostility towards wartime deserters. If non-anonymous punishment were lessened by being more costly, this could be just another example of how remarkable humans are at fine-tuning their behaviour to suit their circumstances.

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