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Information transmission via movement behaviour improves decision accuracy in human groups

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A major advantage of group living is increased decision accuracy. In animal groups information is often transmitted via movement. For example, an individual quickly moving away from its group may indicate approaching predators. However, individuals also make mistakes which can initiate information cascades. How responsive should individuals then be to escaping group members? Increasing responsiveness increases true positives (i.e. escape when a predator is present) but at the cost of increased false positives (i.e. escape when a predator is absent). Conversely, reducing responsiveness decreases not only false positives but also true positives, resulting in a fundamental trade-off in decision accuracy. Here we investigated how socially responsive individuals are to information transmission via movement. We performed a simulated predator detection task using human groups in which humans stepped forward if they wanted to escape. We confirm that this simple movement mechanism allows individuals in groups to simultaneously increase true positives and decrease false positives. The increase in the number of escapees over time during collective decisions depended on the personal information of the group members. Individual predator detection by only a few group members rarely resulted in anyone stepping forward. Individual predator detection by a quarter of the group often resulted in the entire group escaping. Finally, individual predator detection by at least half of the group led to a rapid escape of the whole group. Overall, the increase in the number of escapees over time followed a linear response. Since information transmission via movement is widespread in animal groups, this mechanism is expected to be relevant for many animal groups to improve decision accuracy.

Group living has evolved owing to the many advantages it provides to the individuals that are part of a collective, such as increased safety and increased opportunities for detecting food or finding mates (Krause & Ruxton, 2002; Sumpter, 2010). Such advantages often result from the ability of groups to achieve higher decision accuracy than single individuals (Clément et al., 2013; Conradt & List, 2009; Ward, Herbert-Read, Sumpter, & Krause, 2011).

Animal groups frequently need to make consensus decisions in order to maintain group cohesion and its associated benefits and, in many cases, the information exchange underlying these decisions takes place via movement (Conradt & Roper, 2003; Miller, Garnier, Hartnett, & Couzin, 2013; Strandburg-Peshkin et al., 2013). For example, in fish shoals and bird flocks, an individual moving away from the group indicates to the others its intention to change direction or leave a current location (Beauchamp & Ruxton, 2007; Radakov, 1973). Changes in speed and direction are often the primary ways of information transmission in large groups (Handegard et al., 2012; Katz, Tunstrøm, Ioannou, Huepe, & Couzin, 2011; Sumpter, Buhl, Biro, & Couzin, 2008). Although verbal communication often plays a crucial role in humans, movement alone can also serve as the sole cue in everyday human interactions, as observed in pedestrians at road crossings, where individuals are more likely to jaywalk after seeing another individual doing so (Faria, Krause, & Krause, 2010).

Individuals moving in a given direction can thus provide information to their group members, which can increase collective

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accuracy (Berdahl, Torney, Ioannou, Faria, & Couzin, 2013; Lazarus, 1979; Treherne & Foster, 1981; Ward et al., 2011). In situations involving predation risk, for example, a sudden movement away from the group by some individuals usually indicates the presence of a predator, as shown in fish schools and bird flocks, and can trigger the reaction of the whole group (Cresswell, 1994; Hingee & Magrath, 2009; Kenward, 1978; Lima, 1994; Radakov, 1973). However, individuals might also make mistakes (e.g. false alarms) and this can give rise to cascades of false information, whereby the whole group is led into a wrong action (Bikhchandani, Hirshleifer, & Welch, 1992; Conradt, 2011; Giraldeau, Valone, & Templeton, 2002; Janis, 1982). This raises the question of how sensitive should individuals be to information from their conspecifics, a classic dilemma for decision makers under uncertainty (Beauchamp & Ruxton, 2007; Giraldeau et al., 2002; Lima, 1995; McNeil, Keeler, & Adelstein, 1975; Swets, 1988; Swets, Dawes, & Monahan, 2000; Zweig & Campbell, 1993). The aim of a decision maker is to take an action whenever a particular condition in its environment is fulfilled, but abstain from it when the condition is not fulfilled. In the case of predation risk, for example, an animal should run away in the presence of a predator but not in its absence. However, cues indicating a particular condition (e.g. presence of a predator) may also appear in its absence. Conversely, the condition may be fulfilled without any obvious cues. Increasing responsiveness to such cues leads decision makers to increase their chances of correctly taking the action when the condition is fulfilled (making a true positive, e.g. run away in the presence of predators) but also that of erroneously taking this action in its absence (committing a false positive, e.g. run away in the absence of predators), while reducing responsiveness leads to a decrease in false positives, but at the cost of reduced true positives. This fundamental trade-off in decision accuracy under uncertainty is encountered across many different contexts, including predator detection (Beauchamp & Ruxton, 2007; Lima, 1995) and food detection (Giraldeau et al., 2002).

Recent research has shown that individuals in groups can overcome this fundamental trade-off. Using a mathematical model, Wolf, Kurvers, Ward, Krause, and Krause (2013) predicted that, compared to solitary individuals, individuals in groups can simultaneously increase true positives and decrease false positives whenever individuals employ a quorum threshold in between the average true and false positive rates of the other group members. This prediction was then tested with groups of humans in a simulated predator detection experiment in which participants anonymously expressed their intention to either stay or escape using voting machines, after which they received a summary chart showing the aggregated decisions of all group members and could decide again. The experiment revealed that individuals indeed used a quorum threshold in between the average true and false positive rates of the other group members, thereby simultaneously increasing true positives and decreasing false positives.

However, in many animal groups an individual does not have access to one aggregated response consisting of all the combined independent decisions, but information becomes gradually available. An example of this can be found in antipredator behaviour, in which often one or a few individuals make a decision (i.e. escape), upon which others can decide to either follow this decision or not. Also, in many animal groups, individuals can decide to readjust their decision, if they notice that their decision is not followed by others. Moreover, in most animal groups movement is the prime cue of information transfer. Therefore, we developed an experiment that resembles a more realistic scenario which could be relevant to many social animals. We performed a predator detection experiment in which individuals moved spatially to indicate their choice, allowing the information to be transmitted much more gradually and dynamically. We hypothesized that a group of individuals that can only use movement to indicate preferences is able to increase true positives and decrease false positives. Moreover, we predicted that groups in which only a few individuals detect a predator individually (i.e. low true positive rate) would need a lower fraction of the group indicating escape to cause the group to escape compared to groups in which a large number of individuals detected the predator individually (i.e. high true positive rate). This was predicted because in groups with few individuals detecting a predator, we expected individuals to learn that even low numbers of people escaping can correctly indicate the presence of a predator.

METHODS

Experimental Set-up

Students were recruited from the University of Bielefeld (Germany) and Wageningen University (The Netherlands). The 310 participants in the tests were distributed over 15 groups (average group size 20.7, range 17–23). Informed consent was obtained from all participants prior to the experiment and data collection was anonymous.

Each group was confronted with the following predator detection experiment, resembling the experiment described in Wolf et al. (2013). All individuals in a group were instructed to stand behind a line (4.5 m away from the screen, Fig. 1a) and for 2 s a slide showing 144 fish (aligned in a 9×16 grid) was projected onto a white screen (Fig. 1b). All fish in this school were identical, except one odd fish, which had either six or seven spines (Fig. 1c). The other 143 fish had no spines. The seven-spined fish represented a dangerous predator, whereas the six-spined fish represented a harmless individual, akin to a natural situation in which individuals have to discriminate between harmful and harmless shapes (see e.g. Beauchamp, 2010; Cresswell, Hilton, & Ruxton, 2000). We instructed our subjects to adopt the following decision rule: ‘If you see no odd fish or an odd fish with six spines then it is safe and you should stay. If you see an odd fish with seven spines then it is dangerous and you should escape’. Participants saw the slide of the fish school only once, for 2 s, after which they had 5 s to take an individual decision (polling 1) using an electronic keypad (Key Point Interactive Audience Software for Power Point, version 2.0.142 Standard Edition), ensuring independent votes of participants. Individuals were asked to press 1 if they wanted to escape and they were not allowed to move, gesture or communicate during this stage. Individuals did not receive information about the results of polling 1.

After polling 1, the participants were allowed to make a second decision (polling 2). Two parallel lines, 1 m apart, had been drawn on the floor (Fig. 1a). At the beginning of each trial, participants stood behind the line furthest away from the screen. Individuals were asked to stay behind the line if they wanted to stay, or to step forward (crossing the two lines drawn on the floor) if they wanted to escape (see Fig. 1a). Participants had 12 s to make a final decision and were allowed to move back and forth as often as they wanted during this time. Individuals were not allowed to communicate or gesture during polling 2, but they were able to observe and influence each other by taking into account the movement of their group members. After 12 s, we counted the participants that decided to stay and escape. We also recorded the movement behaviour using a video camera (Sony HDR-XR520V, 25 frames/s) mounted on an elevated tripod next to the screen facing the volunteers in order to get the widest angle and avoid some of the volunteers' movement being masked by others (Fig. 1a). After polling 2, we presented the correct answer on the screen and instructed all participants to move back behind the original line