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The Arena System: a novel shared touch-panel apparatus for the study of chimpanzee social interaction and cognition

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Abstract We report on the development of a novel shared touch-panel apparatus for examining a diverse range of topics in great ape social cognition and interaction. Our apparatus—named the Arena System—is composed of a single multitouch monitor that spans across two separate testing booths, so that individuals situated in each booth have tactile access to half of the monitor and visual access to the whole monitor. Additional components of the system include a smart-film barrier able to restrict visual access between the booths, as well as two automated feeding devices that dispense food rewards to the subjects. The touch-panel, smart-film, and feeders are controlled by a PC that is also responsible for running the experimental tasks. We present data from a pilot behavioral game theory study with two chimpanzees in order to illustrate the efficacy of our method, and we suggest applications for a range of topics including animal social learning, coordination, and behavioral economics. The system enables fully automated experimental procedures, which means that no human participation is needed to run the tasks. The novel use of a touch-panel in a social setting allows for a finer degree of data resolution than do the traditional experimental apparatuses used in prior studies on great ape social interaction.

Keywords Touch-screen · Animal cognition · Social interaction

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Methods for animal social interaction studies should be both simple enough for subjects to comprehend the joint nature of the tasks and complex enough for subjects to generate the nuances of their species-typical behavior and cognition. The history of chimpanzee social behavioral experiments illustrates that this has traditionally been achieved through the use of physical apparatuses that are manipulated separately or in tandem by pairs of subjects. For example, beginning in the first half of the 20th century (Crawford, 1937), and extending to modern-day studies, the predominant method for examining coordination in chimpanzees has consisted of two individuals pulling together on ropes or bars connected to food rewards that are out of arm's reach. In these experimental designs, the goal of capturing out-of-reach food is evident to the participants, whereas the means of achieving it may not be, and as such this has served as a robust platform for examining a range of issues related to coordination, collaboration, and communication (Chalmeau, 1994; Hirata, Morimura, & Fuwa, 2010; Povinelli & O'Neill, 2000), responses to unequal payoffs (Melis, Hare, & Tomasello, 2009), and preferences for joint versus individual action (Brosnan et al., 2011; Bullinger, Wyman, Melis, & Tomasello, 2011). When examining other aspects of social interaction that occur sequentially or require extended bouts of coregulated actions, additional paradigms have been developed, which include alternating buttonpresses (Crawford, 1941), token redemptions (Proctor, Williamson, de Waal, & Brosnan, 2013; Yamamoto & Tanaka, 2009), or moving table mechanisms (Jensen, Call, & Tomasello, 2007a, 2007b).

One common methodological feature of the above-mentioned studies is the necessity of a human experimenter to facilitate many aspects of the experimental procedures, which can include the manual delivery of food, the resetting of the physical apparatuses in-between trials, and the collection of data by hand. As a result, intertrial intervals may be long, unintentional bias caused by the experimenter's behavior may become a factor, and the resolution of the data collected is constrained by the experimenter's observational capacities and possible subjective biases (which are, however, often mitigated by analyzing video recording). Our aim in developing the system described in this article was to create a versatile apparatus capable of automating many of these processes, so that there would be minimal need for a human experimenter to physically manage the procedural protocols during experimental sessions. Our solution was a fully automated apparatus named the Arena System, which enables pairs of chimpanzees to participate in "shared" touch-panel tasks. The system collects choice and latency data using computer software and dispenses food rewards automatically. Its development was inspired by the goals of creating a platform that could (1) reproduce social interaction scenarios in a computerized form, (2) expand the possibilities for future study topics, and (3) offer enhanced control and finer data resolution than do traditional methods.

As compared to physical manipulanda, the Arena System's utilization of a computer touch-panel offers, on the one hand, fully automated experimental events with rapid trial progressions, and on the other, a data-capturing method that measures responses on the millisecond time scale. Importantly, since the system is controlled by a computer that is connected to automatic food dispensers, there is also no need for a human experimenter to handle or place food on a trial-to-trial basis, which carries the potential confounds of shifting the subjects' attention away from the conspecific partner and of introducing unintentional biases (i.e., cues that animals can take from the experimenter's behavior). Finally, the use of a computer at the core of the procedure constitutes a significant leap in terms of the sophistication and flexibility of the tasks administered, which may include pictorial stimuli, moving stimuli, virtual tokens, and many more possibilities for task-design elements that are not or are less readily available in prior social interaction paradigms.

The Arena System

Touch-panel

Figure 1 shows a schematic overview of the design of the system (for photographs of the system as it exists in the laboratory, see Fig. 2). The two participants are situated in adjacent booths with polycarbonate transparent walls on all sides. A 22-in. multitouch monitor (3M C2254PW) mounted in a polycarbonate casing spans across the edge of a common wall, giving the subject in each booth tactile access to half of the screen and visual access to the whole screen. The innovative idea that distinguishes it from prior examples of multisubject touch-panel setups (Martin, Biro, & Matsuzawa, 2011; Subiaul, Cantlon, Holloway, & Terrace, 2004) is the use of a single, "shared" screen instead of dual screens. The shared touch-screen is a more intuitive way for subjects to comprehend the joint nature of the task, since the subjects manipulate the same panel rather than two separate panels. Although the use of a shared touch-panel screen is unique to the Arena System, a similar shared-screen method with non-human primates has been used in prior studies that relied on joysticks as the input devices (Brosnan, Wilson, & Beran, 2012; Washburn, Hopkins, & Rumbaugh, 1990). Unlike the joystick method, the Arena System's use of a touch-panel obviates the need to train subjects about the association between the manipulation of an external object and the movement of a cursor on the screen. Moreover, in a social task setting, witnessing another's physical touches toward stimuli on the screen provides what are likely to be more salient social cues than the movements of an on-screen cursor being controlled by another individual's joystick-directed behavior.

Smart-film barrier

The transparent polycarbonate barrier that separates the two halves of the screen is embedded with a layer of smart-film (UMU film), which is capable of adjusting visibility between transparent and opaque states when AC power is supplied (the latency of the switch is under 500 ms). The smart-film is connected via a copper cable to a digital input/output module [CONTEC DIO-8/8(USB)GY], which in turn is connected through a USB cable to the master PC controlling the experimental events. This innovation serves the purpose of giving the experimenter control over the subjects' ability to see their partner's side of the touch-panel monitor at any stage of the procedure. The use of the smart-film feature may be used for some procedures that require subjects to make independent discrete choices without knowledge of their partners' behavior, as in competitive game-theoretic experiments. It may also be used for social-learning tasks in which a model demonstrates an action to a naïve observer. In such a context, social enhancement caused by the sight of a nearby conspecific may be dissociated from more directed learning processes by alternating between transparent and opaque states as the observer learns from the model. Since the opacity of the screen is controlled by the same experimental software that is running the touch-panel task, the possibility also exists to give the subjects themselves control over the barrier's transparency. For example, in social-learning tasks, naïve learners with control over the barrier's transparency may "choose to learn" from a skilled partner performing model behaviors on the other half of the screen.

Universal feeders

Located directly underneath the touch-panel are two partitioned feeding trays, which are connected through plastic tubing to a pair of universal feeder machines (Biomedica BUF-P-100). Each feeder is responsible for dispensing food

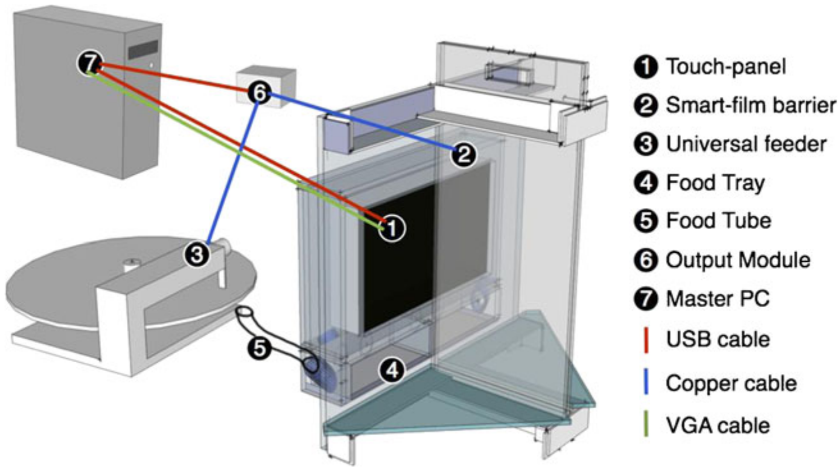

Fig. 1 Schematic overview of the system. The touch-panel is mounted along a wall dividing two separate testing booths

rewards to one of the two food trays accessible by the subjects. The feeders, like the smart-film barrier, are connected via a circuit to a digital input/output module, which is connected to the master PC. The universal feeders are capable of dispensing food that is roughly 8 mm in diameter, at a rate of one rotation every 1,500 ms. The feeding triggers are controlled by the experimental software running on the PC. Additional feeders may be added to the setup so that subjects may be rewarded with multiple kinds of food (or different amounts of the same food) for studies that require differential reward schemes.

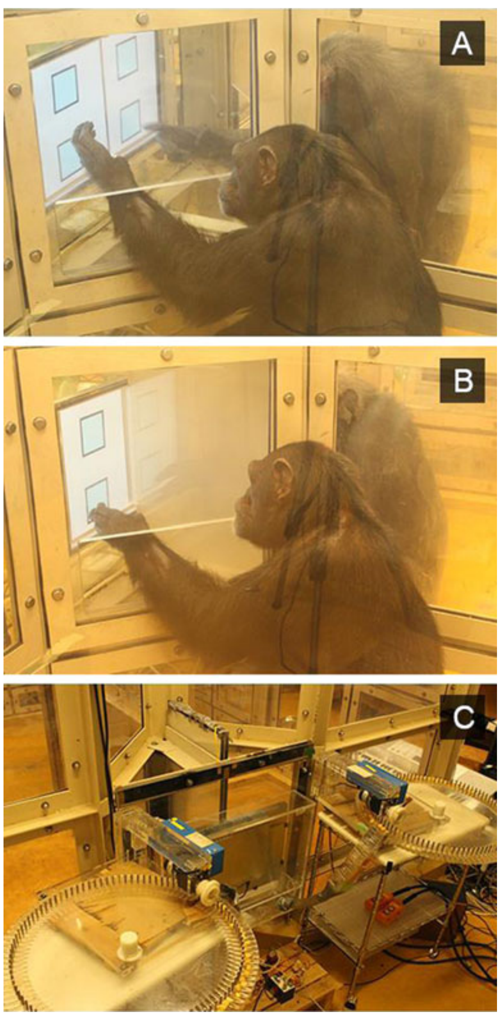

Fig. 2 Photographs depicting two chimpanzees engaged in a shared task. The subjects perform the task while the barrier between them is either in a transparent state (**a**) or an opaque state (**b**). Panel **c** shows the back of the Arena System, where the two universal feeders are located

Software

Experimental events are controlled by a PC (Intel core i5) running the Windows 7 operating system. The experimental software is composed of custom-made Visual Studio Express 2010 vb.net WPF applications, which support built-in multitouch control (for a sample program available for download, see the supplemental materials). Signals sent to the automatic feeders and smart-film barrier are made using the CONTEC API for their DIO-8/8(USB)GY module product.

The Arena System realized: an example procedure for running 2 × 2 normal-form games

Figure 2 shows a photograph of the Arena as it exists in a laboratory setting (for videos of the Arena in use by chimpanzee subjects, see the supplementary materials). To show the utility of the Arena and to illustrate its use through a simple example, we here describe a method for conducting game-theoretic tasks comprising 2 × 2 normal-form games. Behavioral game theory is a mature field of study in human psychology, and a growing one for research on chimpanzee social interaction, in which previous studies have examined the Mini-Ultimatum game (Jensen et al., 2007a; Proctor et al., 2013) and the Stag Hunt game (Brosnan et al., 2011; Bullinger et al., 2011). Here we show a novel method for conducting an iterated 2 × 2 normal-form game of Matching Pennies, which is procedurally equivalent to the Stag Hunt game, differing only in the payoff structure of the choice contingencies. It should be noted that the method described here is likewise applicable to any 2 × 2 choice game, including the Prisoner's Dilemma, Chicken, and Battle of the Sexes (Fudenberg & Tirole, 1991). In contrast to prior chimpanzee 2 × 2 game studies, which have used choice inputs of rope/lever pulls and token exchanges, the example presented here uses stimuli on the Arena System's touch-panel interface as inputs and dispenses food through automatic feeders, thus obviating the need for a human to place food on rope pulls during intertrial intervals or to continually conduct token exchanges. Though ours is the first application of these methods to 2 × 2 games in great apes, a prior study with monkeys playing a 2 × 2 game was conducted by Brosnan et al. (2012) using a similar computerized apparatus involving joysticks rather than a touch-panel. The automated task and reward method also allows for shorter intertrial intervals and for more trials to be conducted in a given period of time, which is closer to the standard experimental economics procedures used in human studies (Camerer, 2003).

Matching Pennies, also known as the Morra Game or Odds and Evens, is the two-choice version of Rock–Paper–Scissors (the task procedure is shown in Fig. 3). Our choice of Matching Pennies as an exemplar is based on the fact that it has a simple payoff structure that results in a winner and a loser on every round. At the start of the game, one player is designated the matcher, and the other player is designated the mismatcher. The matcher sits on the left side of the Arena System, and the mismatcher sits on the right. On each round, each player is presented with two choice stimuli (represented by 8 cm × 8 cm blue squares located at the top and bottom of the screen). The matcher wins an apple cube if the locations of the players' choices match (i.e., if both players touch either the top or the bottom square). Otherwise, if one player chooses the top square and the other chooses the bottom square, the mismatcher wins. After choices are made, the winner's side of the touch-panel displays a yellow background, whereas the loser's side displays a red background. An 8-mm cube of apple is automatically dispensed to the winner's food tray, accompanied by a high- or low-pitched chime (high for matcher, low for mismatcher). The data that are recorded by the computer software include the choices of the participants, as well as the response latencies of their choices.

To familiarize subjects about the outcomes from all possible choice contingencies, the barrier can be kept transparent and forced choice trials may be used (Fig. 4a; for video, see the supplementary materials), whereby instead of the typical total of four choices presented across the entire screen (two on each side), only two are presented (one on each side, each one in either the high or the low position). To probe subjects' knowledge about the task, trials with three total choices may be presented on the screen (Fig. 4b). For example, on the matcher's side, only the top choice is presented, whereas on the mismatcher side, both choices are given, and the

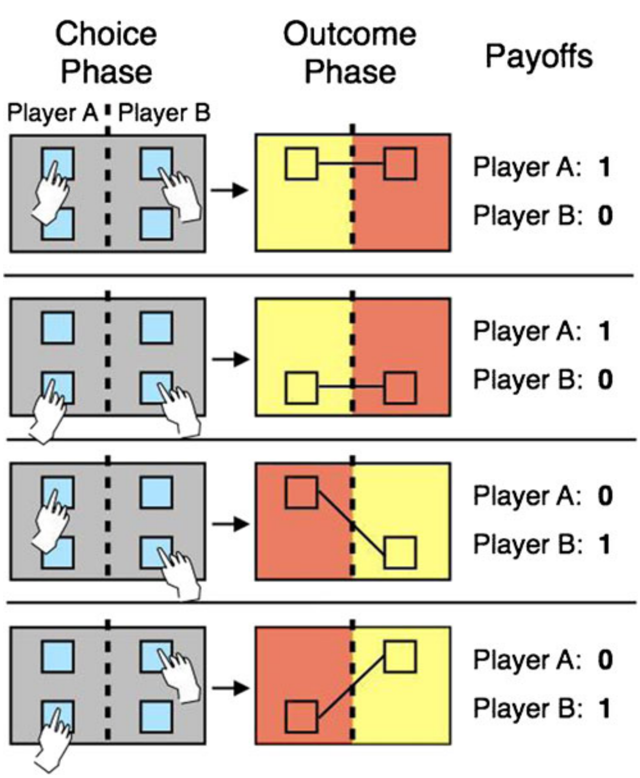

Fig. 3 Schematic of the procedure for a Matching Pennies game. The same procedures is applicable to other 2 × 2 normal-form games. In this example, Player A is the matcher and Player B is the mismatcher

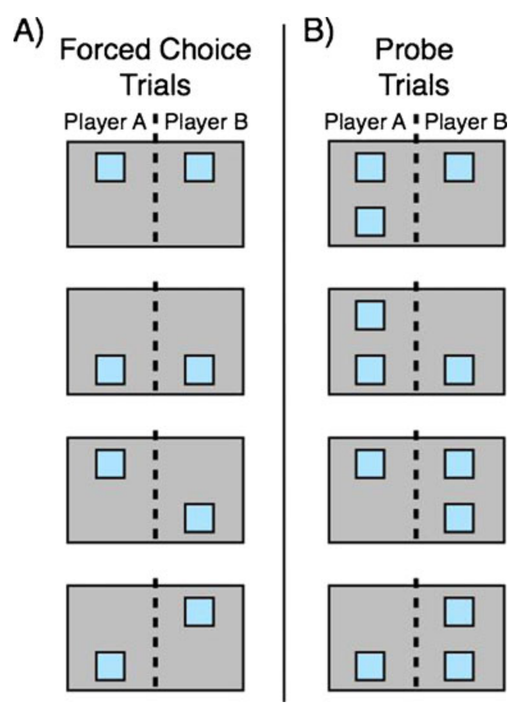

Fig. 4 Examples of trial types for training sessions (**a**) and for comprehension probing (**b**) in a Matching Pennies game

mismatcher should learn to touch the bottom choice. If the players reliably choose the stimuli that result in a victory over repeated bouts of all permutations of probe trial types, it can be inferred that they have a satisfactory comprehension of the game's structure. Experimental sessions may commence by programming the barrier to be made opaque while subjects make their choices, resulting in discrete and independent strategic choices.

Pilot study of Matching Pennies with a single pair of chimpanzees

To show that the Matching Pennies game procedure on our system is feasible not only in theory but also in practice, we present a case of chimpanzees learning the choice contingencies of the game and subsequently playing it over several repeated sessions. Two chimpanzees located at the Primate Research Institute of Kyoto University participated in the experiment: Chloe, a 32-year-old female, played in the mismatcher role, and her 12-year-old daughter Cleo played in the matcher role. The participants voluntarily came to the laboratory booth for testing when called from their outdoor living enclosure. Their care and use during the experiment adhered to the guidelines produced by the Primate Research Institute.

Learning phase

The initial training in the task consisted of exposure to all eight of the training trial types shown in Fig. 4 (four forced choice trial types and four comprehension probe trial types; for video, see Supplemental Video 1). With the barrier between the players kept transparent, each of the trial types was randomly presented five times in a given session of 40 trials. Each participant therefore received ten total comprehension probe trials per session, half of which required a response to the bottom choice, and the other half a response to the top choice. The numbers of correct responses on the ten probe trials for each participant over repeated sessions are shown in Fig. 5. Since half of the total trials were forced choice trial types, each participant could expect a baseline guarantee of a reward on 25 % of the trials per session. To increase motivational levels and expedite the learning process, these forced choice trials were eliminated starting with Session 11, and only probe trials were given in subsequent sessions. This created a scenario in which participants could only gain food rewards by choosing correct responses or by benefiting from the errors of their opponent. The training phase was completed when both participants achieved a score higher than eight out of ten probe trials for two consecutive sessions (shown in Fig. 5).

Game phase

Following training, the participants were given 800 trials of the Matching Pennies game (shown in Fig. 3) over four sessions (200 trials per session). To examine the influence of visual access to the partner's side of the screen on their decision-making processes, usage of the smart-film barrier was employed in half of the sessions, thereby creating two conditions: transparent and opaque (shown in Fig. 2 and Supplemental Video 2). During transparent sessions, the smart-film was kept in a transparent state for the duration of the session. During opaque sessions, the smart-film was kept in an opaque state during the choice phase of each trial and was made transparent immediately after both subjects had performed a choice, thereby enabling them to receive visual feedback about their opponent's choice during the outcome phase of each trial. The two conditions were given in an ABBA design, such that during the first session the smart-film was transparent, followed by two opaque sessions, and then a final transparent session. It was hypothesized that if the transparency state of the smart-film barrier had an influence on the participants' decision-making processes, their performance rates and response latencies should differ between the two conditions. In particular, a transparent barrier state (but not an opaque state) during the choice phase would allow for the possibility of waiting for the opponent to choose first, in order to guarantee a victory for oneself. This strategy is referred to as the *second-mover advantage*. A player's utilization of the second-mover-advantage strategy should be accompanied by longer response latencies during the transparent than the opaque conditions, and by a tendency for second moves to result in wins more often during transparent than during opaque conditions.

The results suggest that the second-mover advantage was utilized by one of the two subjects, Cleo. Her mean response time was significantly longer for the transparent condition than for the opaque condition (Fig. 6a; paired-sample t test, $t = 13.456$, $df = 377$, $p < .05$, one tailed), and the percentage of her total wins that were composed of second moves (Fig. 6d) was significantly greater than 50 % during the transparent condition (binomial test, $p < .05$), but not during the opaque condition. The behavior of Chloe, the other subject, did not show similar tendencies in the direction of a second-mover advantage. The overall impact on the game's outcome caused by only one of the two players using the second-mover strategy is shown in Fig. 6c. Cleo, who displayed significantly more second moves than would be expected by chance during the transparent phase (Fig. 6b; binomial test, $p < .05$), also won at a rate significantly above chance level while doing so (Fig. 6c; binomial test, $p < .05$). The lack of a second-mover strategy by her opponent, Chloe, may have resulted from motivational factors, the relative difficulty of being a mismatcher versus being a matcher

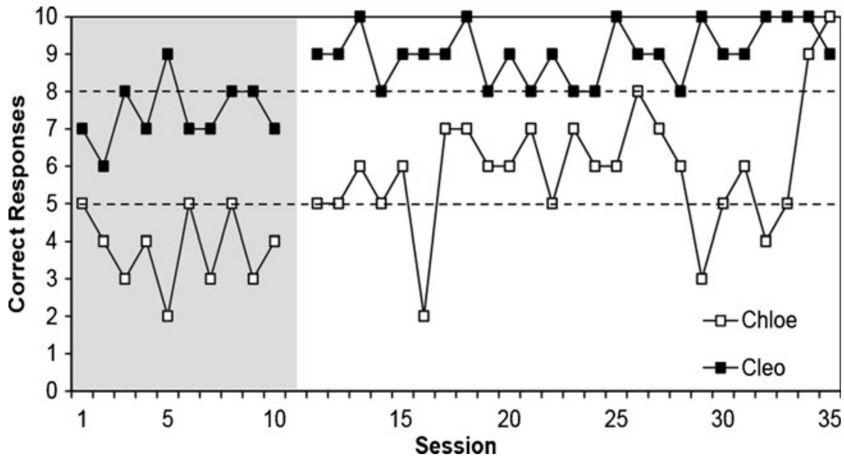

Fig. 5 Performance rates on probe trials during the learning phase of the experiment. The gray area represents sessions in which equal numbers of forced choice trials were given in addition to the probe trials. The white area represents sessions in which no forced choice trials were given. The dashed line located at five correct responses represents chance level, and the dashed line at eight correct responses represents the criterion level

(which is also suggested by Chloe's slower learning rate to achieve the training criterion level), or perhaps from an altruistic tendency to let her daughter win. More detailed studies with longer training and experimental phases may help to elucidate what factors might influence the players' discovery and utilization of the second-mover advantage, as well as to explore a host of other behavioral game theory topics, such as the ability of subjects to exhibit a mixed-strategy equilibrium in their choice patterns (a common topic of human game theory experiments; see Camerer, 2003). For the purpose of this article, which was to demonstrate the efficacy of the Arena System in facilitating a Matching Pennies task, we believe that attainment of the training criterion level by both subjects and the apparent presence of the second-mover advantage in one of the two subjects lend support to the feasibility of our method.

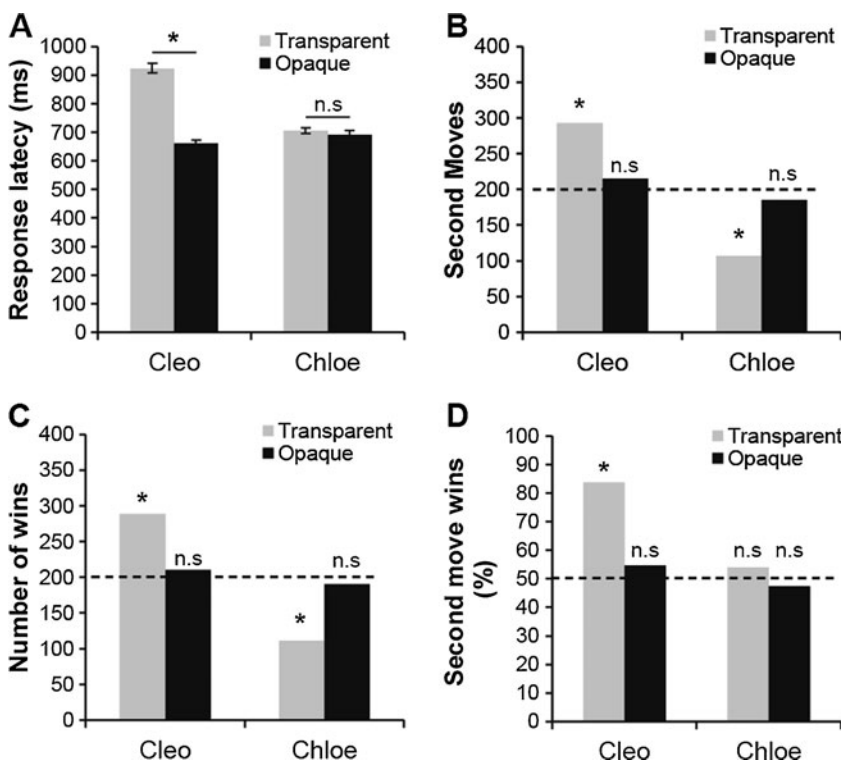

Fig. 6 Results from the Matching Pennies game. (**a**) Response latencies for each subject during the transparent and opaque conditions. (**b**) Total numbers of second moves. (**c**) Total numbers of wins. (**d**) Percentages of total wins that derived from second moves. Note: An asterisk or "n.s." above a bar represents the significance level in a paired-samples t test (**a**) or in a binomial test with a test proportion of .5 and an alpha value of .05 (**b**, **c**, **d**). Dashed lines represent chance level

Summary and outlook

The Arena System represents a novel and innovative system for conducting research on chimpanzee social interaction. In this article, our aims were to describe the Arena System and its advantages and to provide an example of how it may be used to facilitate experimentation, using the example of a behavioral game theory method that is applicable to a class of interactive strategic games. Relative to traditional methods, our system offers many novel features, including a millisecond-scale response latency measurement, automated training procedures, rapid trial progressions, control over visual access to partner behavior, and versatile task design.

The development of the Arena System was inspired by well-proven methods for research on primate cognition composed of computerized tasks with isolated individual subjects. Studies that involve individual-subject tasks have contributed much to the current understanding of primate cognition (Matsuzawa, 2003; Rumbaugh, 1977), notably in the areas of symbolic comprehension (Savage-Rumbaugh, McDonald, Sevcik, Hopkins, & Rubert, 1986), analogical reasoning (Fagot & Thompson, 2011), spatial cognition (Washburn & Astur, 2003), numerical competence (Matsuzawa, 1985), memory (Inoue & Matsuzawa, 2007), and visual perception (Matsuzawa, Tomonaga, & Tanaka, 2006). Tasks for multiple subjects involving touch-panels have also been developed using a dual-screen setup for chimpanzees (Martin et al., 2011) and macaques (Subiaul et al., 2004). Additionally, Washburn and colleagues (Washburn et al., 1990) tested the impact of competition on rhesus monkey behavior in a task that involved two participants "shooting" a target on a shared screen using joysticks. More recently, Brosnan et al. (2012) used an apparatus with joysticks connected to a shared computer screen to explore decision-making in monkeys during an Assurance game. The Arena System combines the multisubject aspects of the shared or dual-screen methods, the versatility of computerized paradigms, and the simplicity of traditional methods involving physical manipulanda such as rope pulling, in which a single object is simultaneously handled by multiple participants.

Although the example task that we describe here was conducted with chimpanzees, application of our method is possible for many more species that are capable of participating in computer touch-panel experiments. Such capacities have already been confirmed in, for example, other great apes (for gorillas, Ross, 2009; for orangutans, Vonk, 2003), as well as for rhesus monkeys (with a touch-panel, Basile & Hampton, 2011; with joysticks, Brosnan et al., 2012; Washburn et al., 1990), capuchin monkeys (Brosnan et al., 2012; McGonigle, Chalmers, & Dickinson, 2003), mandrills (Leighty et al., 2011), baboons (Fagot & Parron, 2010), dolphins (Delfour & Marten, 2005), and dogs (Range, Aust, Steurer, & Huber, 2008). Mixed-species experiments are also a possibility, either by having individuals of two different species located at the same Arena System, or by developing Internet-enabled tasks to facilitate remote interaction between two systems in different locations. Training of naïve subjects and species on how to use touch-panel apparatuses may be facilitated by situating a human experimenter on one side of the system to demonstrate the task procedures, thereby mediating and expediting the animals' learning processes.

In summary, the development of the Arena System represents a promising step forward for examining interactive social cognition and behavior in a fully controlled, autonomous testing environment. We are confident that it offers a versatile platform for making precise measurements about the mechanisms of social interaction in a variety of species.

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