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Liquid Conservation in Orangutans (*Pongo pygmaeus*) and Humans (*Homo sapiens*): Individual Differences and Perceptual Strategies

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Four orangutans (1 juvenile, 2 subadults, and 1 adult) and ten 6–8-year-old children were tested in 4 liquid conservation tasks of increasing levels of difficulty. Task difficulty depended on the type of transformation (continuous vs. discontinuous quantities) and the relative contrast between the shapes of the containers. Results indicate that orangutans did not display conservation in the strict sense; instead they showed "partial" conservation (intermediate reactions according to J. Piaget & B. Inhelder, 1941). In contrast, some of the children provided evidence of conservation in all 4 tasks, showing "true" or logically necessary conservation in the original sense proposed by J. Piaget and B. Inhelder (1941). Although orangutans did not show conservation in the strict sense, as J. Piaget (1955) and others have generally agreed it should be defined, orangutans behaved as individual and creative problem solvers, adopting different perceptual strategies depending on the task.

Detecting regularities in the environment is arguably a major functional orientation of any biological system. The detection of invariance is an important aspect of cognition. In humans, Piaget (1955) proposed that the first landmark development of the ability to detect invariance and to reason beyond the information given by perception is achieved by the child at the end of the sensorimotor period with the achievement of object permanence. *Object permanence* refers to the ability to reason about objects that are temporarily out of sight. Prior to achieving this insight, children behave as if objects that have disappeared before them under an occluder (e.g., a cloth) no longer exist. This interpretation is based on Piaget's observation that children fail to search for the hidden object under the occluder (but see Baillargeon, Spelke, & Wasserman, 1985, for a different interpretation). With the achievement of object permanence at around 18 months of age, however, the child is described by Piaget as behaving as if an object temporarily out of sight continues to exist, systematically searching for hidden objects in a variety of contexts.

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Within the Piagetian framework, another major achievement in the development of children's ability to detect invariance occurs around 7–8 years of age, during what Piaget (1955) described as the concrete operational period. This period is marked by the development of a new ability to reason about transformations of objects, and in particular the understanding that continuous and discontinuous quantities of liquids—their substance, volume, length, or number—are conserved independently of the perceived transformations. In their original work on liquid conservation, Piaget and Inhelder (1941) presented children aged 5–8 years with two identical transparent containers (A and B) containing the same amount of liquid. Once the child recognized the equivalence between A and B, the content of B was poured and equally divided into two smaller containers. Following the transformation the child was asked whether there was still the same amount of liquid in the two smaller cups compared with A. Next, either one or the two small cups were further poured and equally divided into two or four even smaller cups. Again, the child was asked whether there was still the same amount of liquid contained in all the small cups compared with A. Based on interviews with children in this experimental situation, Piaget and Inhelder described three general stages. At 5–6 years of age, children demonstrate an absence of conservation, reasoning that following transformations into smaller quantities, the original amount is changed, either by becoming larger or smaller. By 6–7 years of age, children show intermediary reactions, conserving up to the first transformation, but reversing their choices based on conservation when the liquid is further divided into smaller quantities. Finally, by 7–8 years of age, children demonstrate necessary conservation, inferring the invariance of quantity based on the logic of identity, compensation, or reversibility.

From a comparative perspective, it is important to know whether this achievement is specific to humans. Can our closest primate relatives also reason as problem solvers in the context of a task requiring the conservation of continu-

ous and discontinuous quantities? Only a few studies have addressed this question using different methodologies. Czerny and Thomas (1975) have shown that adult squirrel monkeys (*Saimiri sciureus*) possess at least the prerequisite for conservation, because they are able to provide accurate same–different judgments regarding pairs of identical objects differing in volume. Also, Thomas and Peay (1976) demonstrated the ability of adult squirrel monkeys to make same–different judgments with regard to length conservation tasks. Similar results have been reported with two rhesus monkeys within the paradigm of learning set training (Pasnak, 1979). Woodruff, Premack, and Kennel (1978) showed that an adult female chimpanzee (*Pan troglodytes*) trained to use plastic tokens corresponding to the words *same* and *different* conserved quantity of liquid and matter despite a transformation of shape, but failed to show number conservation. The authors argued that the subject, Sarah, based her decisions on inference rather than merely perceptual cues. This interpretation is based on the fact that she failed to correctly estimate quantity once the transformation had taken place without the possibility of exploring the initial quantities. Furthermore, she was able to correctly estimate the relation (same–different) between containers after some quantity of liquid was added or subtracted from the initial containers. Unfortunately, the use of same–different tokens to solve conservation tasks does not allow for an analysis of the direction of a difference detected by their subject, and therefore provided limited information regarding the type of information taken into consideration by the animal to provide a different judgment.

Finally, Muncer (1983) tested two juvenile chimpanzees on liquid and number conservation. Only 1 subject manifested liquid and number conservation by choosing above chance the largest of two volumes regardless of their perceptual appearance. In the most stringent test, this subject continued to choose the largest of two volumes despite the fact that the container with the largest amount appeared to have less (i.e., lower liquid height) after the transformation. Muncer also indicated that the chimpanzee based her judgment on inference rather than on perceptual estimation on the basis of her inability to correctly estimate quantities when she was only showed the final state of the containers after the transformation had taken place. Despite Woodruff et al.'s (1978) and Muncer's results in support of conservation, Thomas and Walden (1985) indicated these results should be taken with caution because they were not based on an assessment of the strategies (e.g., identity, compensation, and reversibility) used by subjects to solve the task. Such an assessment would require the use of certain language skills that subjects (at least Muncer's subject) did not possess.

Overall, many questions remain unanswered regarding the general ability of nonhuman primates to reason about the invariance of physical quantities in conservation tasks. First, it is not known how this ability compares with the reasoning developed by children at the concrete operational stage. The idea of conservation was initially developed in children, yet no direct comparison between human and nonhuman animals (i.e., using the same materials and procedure) has been attempted. Second, although both Woodruff et al. (1978) and Muncer (1983) suggested that inference rather than perceptual estimation was responsible for their subjects' conservation responses, it is not clear whether the inferential strategies used by their subjects entailed the logical necessity described by Piaget and Inhelder (1941). Third, the extent to which this reasoning generalizes across different liquid conservation tasks and across different individuals of the same species is also an open question given that previous studies have used a single task with 1 or 2 subjects only. Of particular interest is the study of individual differences that may provide some valuable information regarding the strategies used by the subjects to solve the different tasks. Finally, the study of liquid conservation in orangutans adds a valuable piece of information to comparative cognition because to date, chimpanzees and squirrel monkeys are the only nonhuman animals whose performance on Piagetian conservation tasks has been reported.

The present research is an attempt to address these questions by comparing the performance of a group of orangutans (*Pongo pygmaeus*) and a group of children on various liquid conservation tasks. In the first five experiments, liquid conservation tests of increasing complexity were administered to the orangutans. For comparison, the sixth experiment tested children in the various liquid conservation tasks used with the group of orangutans. We based our testing of liquid conservation in orangutans on two behavioral inclinations in these animals: pointing to request food (e.g., Call & Tomasello, 1994) and preference for the largest of two quantities of food (see Menzel & Draper, 1965). Orangutans can learn to request things from the experimenter by pointing at them with one hand. Furthermore, when placed in a choice situation with two separate cups containing differing amounts of valued food, they tend to request the one they identify as containing more. The combination of an ability to communicate requests by means of pointing and the inclination to choose more allowed us to test liquid conservation in these nonverbal animals and compare their performance with some children.

Experiment 1

As a baseline for the procedure used throughout the study, this first experiment was aimed at testing and establishing the general inclination of orangutans to request by pointing to the largest of two volumes of liquids for drinking.

Method

Subjects. Four orangutans (*P. pygmaeus*) housed at the Yerkes Regional Primate Research Center served as subjects. They included 1 juvenile mother-reared male (Tiram); 1 subadult male (Tombak) and 1 subadult female (Puti), both nursery reared; and 1 young adult male (Chantek) who had been mother reared until 9 months of age, when he was transferred for several years to the University of Tennessee at Chattanooga where he became part of a sign language and cognitive development project (see Miles, 1990, for additional information). Chantek had received some

conservation testing prior to this study, but the results of that study have not been published (H. L. Miles, personal communication, October 10, 1995).

All of these subjects were housed in pairs. Chantek and Tiram were individually tested in the presence of other subjects who were not included in the present study, and Puti and Tombak were separated before testing was conducted. The cages had an indoor and outdoor area with a total living space of 30 m^2. Subjects were fed three times a day on a diet of fruit, vegetables, and monkey chow. Water and monkey chow were available ad libitum, and subjects were not food deprived during testing.

Apparatus. In successive tests, the experimenter presented to the subjects various pairs of identical or different containers with either equal or unequal quantities of fruit juice (0, 45, or 90 ml) mixed with 50% water. (Note that juice is a treat for orangutans.) Two different drinking containers were used in the tests. Both were transparent plastic cups (disposable wine or champagne cups) with bases and stems. One was an inverted cone with a height from top to bottom of 22.5 cm, a top diameter of 6 cm, and 180 ml of total capacity (champagne cup). The other was a cylinder with a height of 10 cm, a diameter of 7.5 cm, and a total capacity of 270 ml (wine cup). In comparison to the wine cup, which was short and wide, the champagne cup was tall and narrow. Perceptually, the same quantity of juice poured in either cup provided a marked apparent contrast in the liquid's height. The experimenter presented the cups in front of the subject on a wooden platform (70 cm × 25 cm) raised 30 cm above the ground, where the subject was seated.

Procedure. Prior to actual testing, all subjects except Chantek were trained to request a particular object by pointing. This was easily accomplished in all 3 orangutans by holding a cup with a certain amount of juice close to the fence in front of the subject. When the subject tried to reach for it by sticking his or her fingers through the cage toward the cup, usually in a palm down or side position, the experimenter offered the juice to the subject by pouring it in his or her mouth. Gradually, the experimenter increased the distance between the cup and the cage until the cup was positioned on the platform at a distance of 30 cm from the cage. In the present experiment, all subjects learned to point in one single session lasting approximately 40 min. The criteria for acquisition of pointing consisted of the subject pointing in 10 successive trials to request juice with a delay of less than 10 s after presentation.

The remaining subject (Chantek) already pointed proficiently at the beginning of the present study (see Call & Tomasello, 1994; Miles, 1990). All subjects reached the pointing criteria before actual testing began. In all subsequent tests, the experimenter placed first, close to one another, a pair of empty transparent cups in front of the subject, then poured from two opaque containers a predetermined quantity of juice into each of the cups (see Figure 1). Before pouring the predetermined quantities of juice, the experimenter made sure that the subject was oriented toward and apparently looking at the containers. In case of distraction, the experimenter waited until the subject was looking at the cups. After pouring, the experimenter moved each cup 50 cm apart and waited for the subject to point to one of the cups. Note that this separation helped the experimenter to decide which cup the subject was pointing to. After the subject pointed to one of the cups, the experimenter offered the content of that cup to the subject by pouring it into his or her mouth through the cage. After the subject drank the juice, the experimenter removed the remaining cup from the platform and wrote down the subject's choice. If the subject subsequently pointed toward the remaining cup, the experimenter ignored the gesture, removed the cup from the platform, and conducted the next trial. Throughout testing, the experimenter wore a baseball hat on which the bill shaded his eyes and prevented subjects from obtaining any cues in regard to the experimenter's gaze orientation.

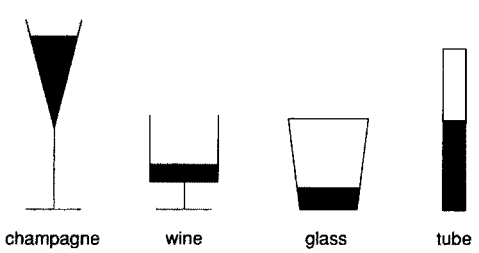

Figure 1. Containers used in the study.

As shown in Figure 2, a first test involved the presentation of a pair of identical containers with unequal quantities (Test A: 0 ml and 45 ml). The second test consisted of the presentation of identical containers with unequal quantities, both cups containing something (Test B: 45 ml or 90 ml). A third test consisted of the presentation of different containers with equal quantities (Test C: 45 ml or 90 ml). Finally, a fourth test consisted of the presentation of different containers with unequal quantities (Test D: 45 ml and 90 ml). Both the position of the largest quantity of juice and the type of cup were counterbalanced for left–right location across trials. Each subject was tested in 11 sessions of approximately 30 min each. In each session, subjects were presented 8 trials in a random order (2 trials of each test type). Overall, we presented 84 trials (24 trials per test) except for Test A, in which only 12 trials were conducted.

Results

Figure 2 presents individual data on the percentage of trials on which the largest of the two quantities of liquid was chosen. Results show that when presented with unequal quantities in identical containers (Figure 2, Tests A and B), all subjects systematically chose the cup containing the largest amount of juice (binomial test: $ps < .05$ in all cases; Test A: $n = 12$, Test B: $n = 24$). As shown in Figure 2 (Test C), when choosing between a pair of different containers, each with the same quantity of liquid, subjects' choices were unmistakably at chance level with the exception of Tombak, who approached significance (binomial test: $p = .063$, $n = 24$). Finally, for Test D, all subjects but one (Puti) persisted in systematically choosing the largest quantity of liquid (binomial test: $ps < .05$ in all cases, $n = 24$), despite the different shape of the containers, which sometimes provided counterintuitive level contrasts (level of lesser amount appearing higher).

Although subjects consistently selected the largest amount of liquid across tests, it is conceivable that they might have learned to select it by mere trial and error in the course of testing. To assess the eventuality of such learning, we compared the number of errors committed in the first block of trials with the second block of trials in Tests B and D. We pooled the data from these tests because they yielded similar results. Thus, each block represented 24 trials (12

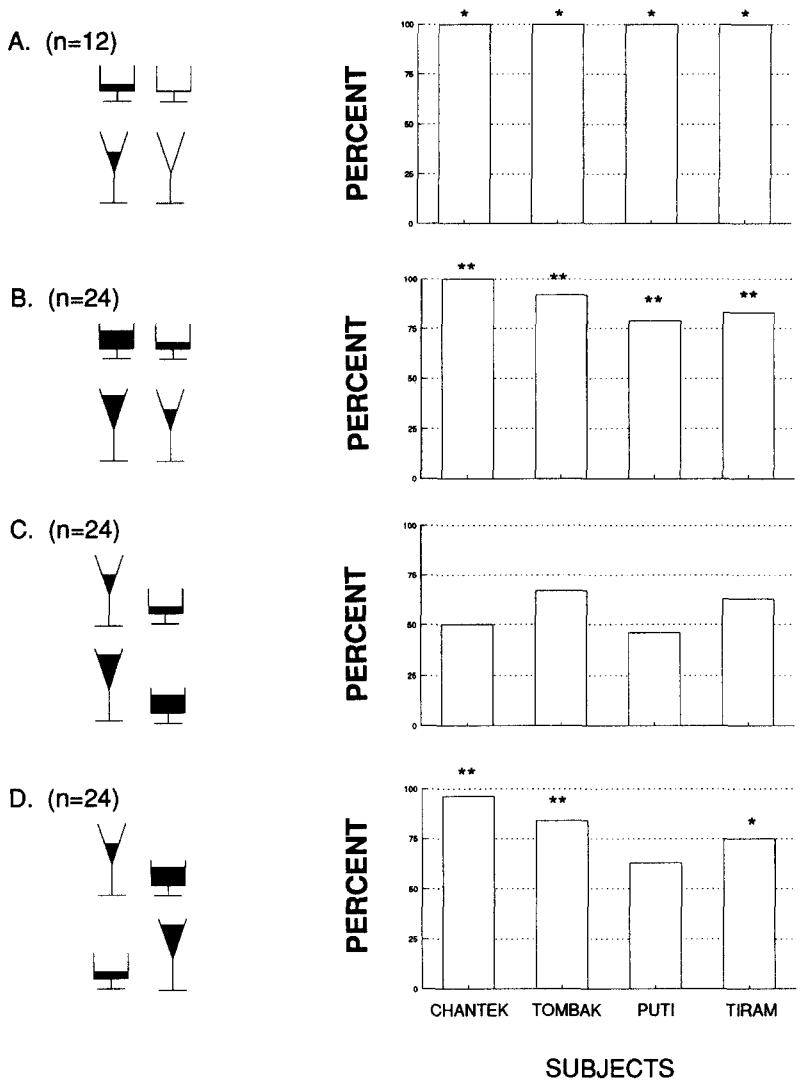

Figure 2. Percentage of trials on which subjects selected the container with the largest liquid quantity. Note that Test C depicts the percentage of trials in which subjects chose the champagne cup over the wine cup even though identical quantities of liquid were presented. Champagne and wine cups were used, and liquid quantities were 45 ml and 90 ml. $*p < .05$. $**p < .01$.

trials × 2 tests). No significant differences between the first and second block of trials were found for all 4 subjects (Puti: 7, 7; Tiram: 7, 3; Chantek: 0, 1; and Tombak: 5, 1 for Blocks 1 and 2, respectively; binomial tests not significant in all four cases). Furthermore, we conducted a more detailed analysis of the distribution of errors within the first block of trials by dividing the data into four blocks, with each block representing 6 trials (3 trials × 2 tests). Although the small numbers of errors prevented any statistical analysis, errors appeared uniformly distributed across blocks (Puti: 2, 3, 2, 0; Tiram: 2, 3, 2, 0; and Tombak: 2, 1, 0, 2 for Blocks 1, 2, 3, and 4, respectively). Overall, these post hoc analyses do not provide any evidence for trial-and-error learning.

Discussion

The results of this first experiment confirmed that all subjects pointed systematically to the cup containing more liquid. Furthermore, except for 1 subject (Puti) in one of the tests, this choice was unaffected by the shape of the containers. When confronted with two different cups containing the same amount of liquid but providing contrasting levels of liquid, all animals pointed randomly to one of the two containers. These results confirmed the systematic pointing of the animals toward the largest volume and indicated that this behavior occurs independently of the containers' shapes.

Pouring equal quantities into different containers is a

method that has been traditionally used in tests of liquid conservation. However, such procedure entails clinical (verbal) interview of the subject regarding his or her judgment following the transfer of liquid into different containers. Such an interview is obviously not possible with nonhuman primates. The pointing technique used in the present research dictates the use of unequal quantities in the context of "overconservation" tasks (Bryant, 1972; Muncer, 1983). With equal quantities, we showed that orangutans pointed randomly to either container. This randomness may be difficult to interpret as a sign of conservation. It could mean that the animal is expressing conservation or, on the contrary, it could also mean that the animal makes random choices that are not based on any strategy linked to conservation. In contrast, if pointing is systematically biased toward the greater of two unequal quantities, it is interpretable as a clear communicative gesture toward the largest of two volumes. This systematic bias will be used to test liquid conservation in the following experiments. However, the use of overconservation tasks may carry with it a potential confound. Transferring unequal quantities to different containers provides subjects with perceptual cues corresponding to the timing and flow of the actual pouring. In principle, subjects could use such cues to systematically track the greater of two quantities following transformation, independently of any conservation ability. The next experiment was designed to test for the eventual use of such perceptual cues by the orangutans in liquid conservation tasks involving different quantities.

Experiment 2

In Experiment 1, subjects tended to choose the largest of two liquid quantities regardless of the shape of the two containers. As mentioned earlier, the use of different quantities of liquid provides extra perceptual cues besides the mere visual appearance of the liquid in the containers after the transformation. These cues include pouring duration, the sound produced by pouring different quantities, and the actual flow during the transfer of the liquids. The present experiment was designed and conducted to control for these cues. Different liquid quantities were poured into identical opaque containers. The opacity of the containers eliminated any visual cues aside from actual transfer of liquid. In this situation, if subjects systematically pointed toward the largest of the two quantities following the transformation, it would indicate that they are using the perceptual cues linked to the actual liquid transfer. Conversely, a failure to systematically point to the largest quantity would support the idea that subjects do not detect and use these perceptual cues.

Method

Subjects. Four orangutans were tested. In addition to Puti, Tombak, and Chantek (see Experiment 1) a new adult male named Teriang was used. Teriang was trained to point to request liquid in the same way as the other subjects (see Experiment 1 for details). Teriang replaced Tiram, who was not available for testing at the time this experiment was run.

Apparatus. We used two pairs of identical opaque plastic cups ("glasses") with a height from top to bottom of 10 cm, a top diameter of 7.5 cm, and 280 ml of total capacity and one identical pair of circular pieces of cardboard (8 cm in diameter) to cover the pair of glasses following the liquid transfer. These two pieces of cardboard prevented subjects from perceiving the liquid's height from above following the transformation. Subjects were tested with four different quantities of liquid: 30, 45, 60, and 90 ml.

Procedure. The procedure was analogous to Experiment 1 with the only difference being that opaque containers were used and the pouring time varied according to the quantity that was poured (constant pouring velocity). The experimenter placed one of the pairs of opaque containers on the platform and poured two predetermined quantities into each of these containers from another pair of containers. The timing of pouring depended on the quantity of liquid being poured: the larger the quantity, the more time it took to transfer it from the initial container to the container located on the platform. As a result the flow of liquid from the initial opaque container to the opaque container on the platform was constant at approximately 10 ml/s (e.g., 60 ml of juice were transferred between containers in 6 s). Pouring time was controlled by the experimenter using a reliable counting technique. Following each transfer of liquid, the experimenter covered the container on the platform with a piece of cardboard. Once both transfers were done, the experimenter followed the same steps detailed in the previous experiment. The position of the largest quantity was counterbalanced for left–right location across trials. Overall, the experimenter conducted 24 trials per subject, comparing the four quantities in three different combinations: 30 versus 60 ml, 45 versus 90 ml, and 60 versus 90 ml. Each of these three combinations was presented eight times.

Results

Results indicate that all 4 subjects pointed to either containers at random during the test. The percentage of trials on which each subject chose the largest of the two quantities of liquid was as follows: Chantek, 62%; Tombak, 71%; Puti, 46%; and Teriang, 50%. None of these values were significant (binomial test: $ps < .05$ in all cases, $n = 24$). Note that the results of Tombak approached significance ($p = .063$).

A comparison of the number of errors during the first and second block of 12 trials yielded no significant differences between blocks for any of the 4 subjects (Puti: 6, 7; Teriang: 6, 6; Chantek: 3, 6; and Tombak: 4, 3 for Blocks 1 and 2, respectively; binomial tests not significant in all four cases). A more detailed analysis of the distribution of errors within the first block of trials conducted by dividing the data evenly into four blocks produced analogous results. Errors were uniformly distributed across trial blocks (Puti: 2, 1, 1, 2; Teriang: 1, 1, 2, 2; Chantek: 1, 1, 1, 0; and Tombak: 1, 0, 1, 2 for Blocks 1, 2, 3, and 4, respectively). Again, these post hoc analyses do not provide evidence for trial-and-error learning during the test.

Discussion

Results of this experiment clearly indicate that none of the 4 subjects systematically used the pouring cues to select the

largest of two transferred quantities of liquid. Subjects did not appear to use the cues provided by the timing or by the sound produced by the pouring of different quantities of liquid in the absence of the visual appearance of the liquid height following the transformation. These results control for the possible confound of such cues in overconservation tasks (i.e., conservation tasks using unequal quantities) and therefore demonstrate that the use of unequal quantities is a valid procedure to test liquid conservation in orangutans.

Experiment 3

In Experiment 1, subjects tended to choose the largest of two volumes of liquid, regardless of the shape of the two containers. The present experiment further investigated the reliability of such behavior in the context of an additional visible transformation. In particular, after the subject made his or her choice for one of the two cups (as in Experiment 1), the liquid was subsequently poured into two new cups. The subjects then made a second and final choice, after which the content of the chosen container was offered to the animal for drinking. In comparison with Experiment 1, there was a double transformation, hence an increased complexity associated with this task. In particular, subjects were required to track two transformations, therefore having to bypass the perceptual contrasts between the apparent level of the liquids twice.

Method

Subjects and apparatus. The subjects and apparatus were the same as in Experiment 1.

Procedure. The procedure was the same as in Experiment 1. However, following their first choice, the experimenter did not immediately offer the chosen cup to the subjects for drinking. Instead, the experimenter placed two new empty cups, side by side, in the middle of the platform. He then poured the contents of each of the cups situated on the extreme left and right of the platform into the adjacent new cups. Then, the experimenter removed the old empty cups and put forth the new filled cups, moving them to the ends of the platform. The experimenter then waited for the subject to point again. Following this second choice, the experimenter offered the contents of the chosen cup, recording which one it was.

As illustrated in Figure 3, a first test consisted of the presentation of different containers with unequal quantities (90 ml and 45 ml) followed by a second transformation into a pair of identical containers. A second test consisted of the presentation of identical containers with unequal quantities (90 ml or 45 ml) followed by a transformation into a pair of different containers. Note that in both tests, only one container changed in shape in the second transformation. A third test consisted of the presentation of different containers with unequal quantities (90 ml or 45 ml) followed by a second transformation in which both containers changed in shape. In each of three sessions, a subject received 4 trials of each of the three tests (for a total of 12 trials per test). Overall, the experimenter administered Tests A and C 12 times and Test B 24 times to each subject in a counterbalanced order (see Figure 3). As in Experiment 1, the location of the cups was counterbalanced across trials for both the first and second transformations.

Results

As shown in Figure 3, following the first transformation, all subjects tended to choose systematically the cup containing the largest quantity of liquid in all three tests (binomial tests: $ps < .05$ in all cases, $n = 12$). These results replicate those of Experiment 1. Following the second transformation, all subjects persisted in systematically choosing the largest quantity in all three tests (binomial tests: $ps < .02$ in all cases, $n = 12$). The extremely low number of errors in this test did not warrant any post hoc analyses of error frequency over trial blocks.

Discussion

The results of Experiment 3 confirmed that all subjects tended to point systematically to the cup containing more liquid. As was the case in Experiment 1, animals showed that this behavior occurred independently of the containers' shape. Furthermore, all animals continued to be accurate in their choice following two transfers of the liquid into different-shaped cups. Overall, these results provided further support to the demonstration that all subjects chose the greater quantity of liquids independently of the various containers' shapes, thus being capable of bypassing a variety of perceptual contrasts between the various containers and liquid quantities.

Experiment 4

After demonstrating the subjects' ability to choose the largest of two volumes after two consecutive transformations, we investigated further the independence of the subjects' choice toward the largest quantity of liquid following two transformations with a new set of cups and different amounts of liquid that provided greater perceptual contrasts.

Method

Subjects. The subjects were the same as in Experiment 1.

Apparatus. We used two different types of containers. One was a regular plastic cup ("glass") with a height from top to bottom of 10 cm, a diameter at the top of 7 cm, and 320 ml of total capacity. The other was a narrow test tube with a height of 15 cm, a diameter of 2.5 cm, and a total capacity of 60 ml, mounted on a cork for vertical support. Perceptually, the same quantity of liquid poured in each of the containers provided a marked perceptual contrast in height, even greater than the one produced by the containers used in the first two experiments. Aside from the cups, the rest of the apparatus was identical to the one used in the preceding experiments. For this experiment, subjects were tested with three different quantities of liquid: 30, 60, and 90 ml.

Procedure. The experimenter followed the same steps as in Experiment 3, pouring two predetermined quantities in each of two identical plastic glasses during the first transformation. Again, the experimenter did not offer the first cup that the subject chose to him or her for drinking. Then the experimenter transferred the contents of the two cups into a new set of cups (second transformation). The contents of the cup chosen by the subject following the second transformation were then offered for drinking by trans-

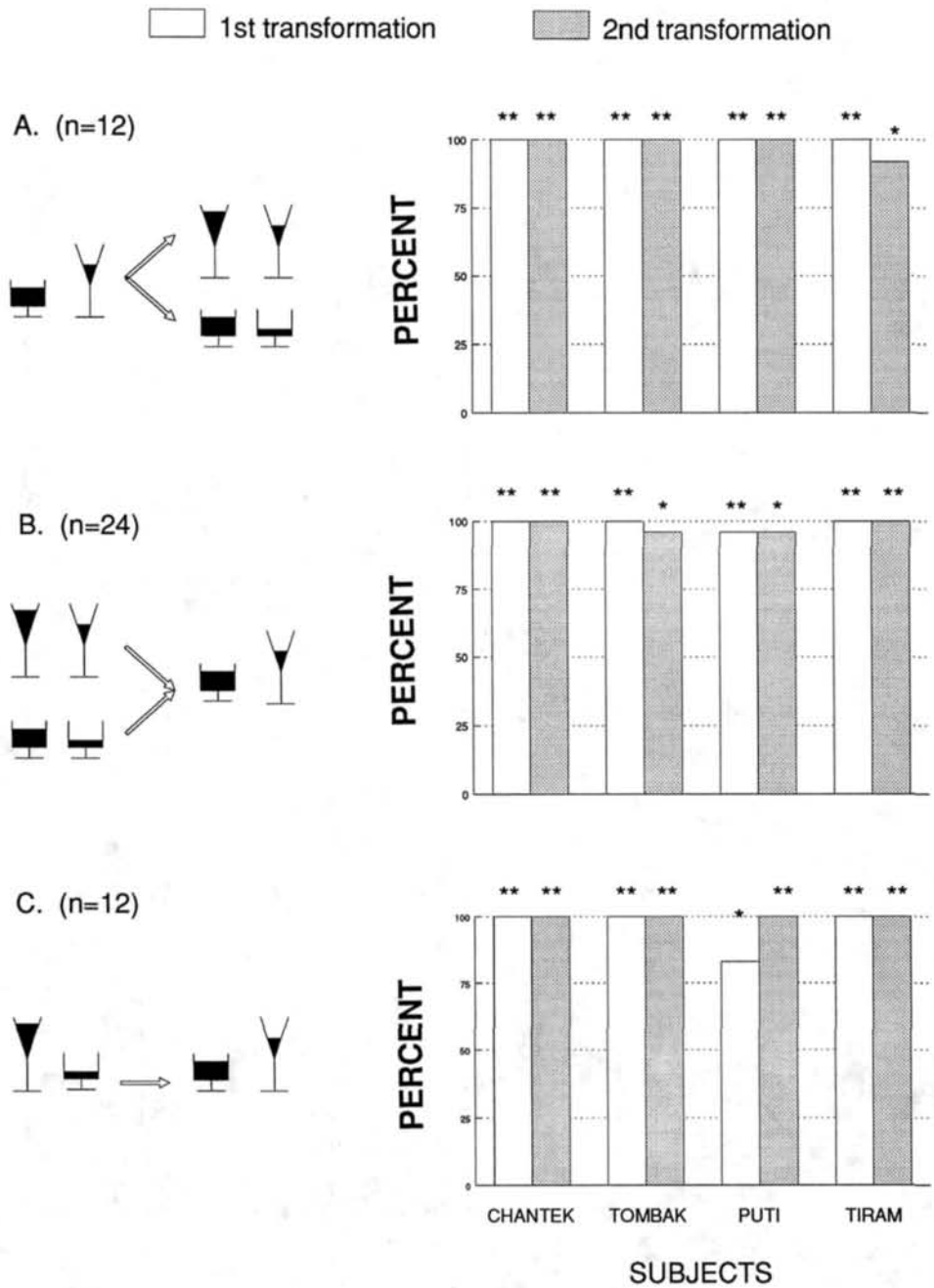

Figure 3. Percentage of trials on which subjects selected the container with the largest liquid quantity after the first and second transformation. Champagne and wine cups were used, and liquid quantities were 45 ml and 90 ml. $*p < .05$. $**p < .01$.

ferring the chosen quantity into another glass cup (different from the experimental ones). This final transfer was implemented to control for the possibility that subjects might have preferred to drink from a particular shaped cup, independent of quantity.

As illustrated in Figure 4, the experimenter administered three different tests. In the first test, subjects first chose between 60 ml and 30 ml of liquid in a pair of identical glasses and then chose between 60 ml in the narrow container and 30 ml in another wide container (test with no potential perceptual conflict). In the second test, the first choice was again between 60 ml and 30 ml of liquid in the set of wide glasses, and the second choice was between the 60-ml quantity poured this time into another wide container and the 30-ml quantity poured into the narrow container (test with potential perceptual conflict). In Test C, the first choice was between 90 ml and 60 ml of liquid in the set of wide glasses, and the second choice was between the 90-ml quantity poured into another wide container and the 60-ml quantity poured into the narrow container (test with potential for even greater perceptual conflict.)

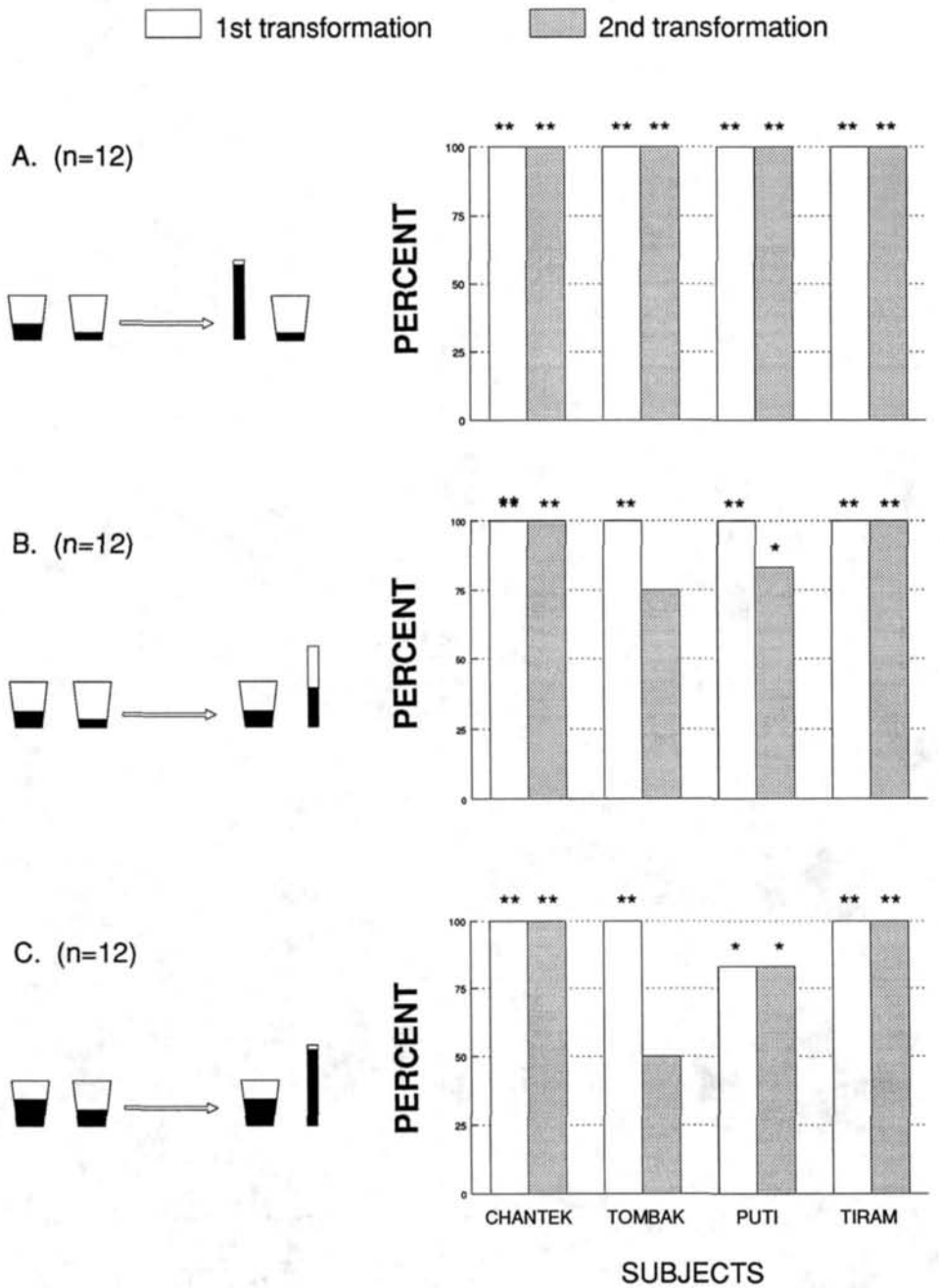

Figure 4. Percentage of trials on which subjects selected the container with the largest quantity of liquid after the first and second transformation. Glass and tube containers were used, and liquid quantities were 30, 60, and 90 ml. $*p < .05$. $**p < .01$.

In each of three sessions, subjects had four trials of each test. Overall, each subject was administered the three tests 12 times in a counterbalanced order. As in the previous experiments, the location of the cups was counterbalanced across trials for both the first and second transformation.

Results

Following the first transformation, all subjects chose systematically the largest quantity (binomial tests: $ps < .05$ in all cases, $n = 12$). These results confirmed that subjects systematically chose the largest of two liquid quantities contained in identical cups.

Following the second transformation, all subjects continued to choose systematically the largest quantity of liquid when the smallest (30 ml) or the largest (60 ml) quantity were transferred into either the wide or the narrow container (Figure 4, Tests A and B; binomial tests: Tombak, $p < .08$; all other $ps < .02$, $n = 12$). Regarding the second transfor-

mation in Test C, which involved larger quantities and corresponded to a greater perceptual contrast of level height, all subjects but one (Tombak) continued to point systematically toward the larger of the two quantities (binomial tests: $ps < .05$ in all cases, $n = 12$).

A comparison of the number of errors observed in the first block of six trials with the second block of six trials revealed no significant differences between blocks for any of the 2 subjects who showed errors in the second transformation trials (see Figure 4; Puti: 3, 1 and Tombak: 4, 5 for Blocks 1 and 2, respectively; binomial tests not significant in both cases). Furthermore, an analysis of the first two 6-trial blocks also yielded no evidence of a decrease in error distribution over trials (Puti: 2, 1 and Tombak: 1, 3 for Blocks 1 and 2, respectively). Again, these results do not support trial-and-error learning.

Discussion

With the new set of cups providing even greater perceptual contrasts between the level of liquid, subjects persisted in pointing systematically toward the largest of the two quantities, hence taking into consideration the height and width of the containers. However, at least for 1 subject, this persistence broke down with the transformation that produced the largest perceptual contrast between liquids' level. This latter result suggests that the liquid conservation manifested by the subjects in their pointing might be a "pseudo" rather than a true conservation in the Piagetian sense, still dependent on perception and not implying any logical necessity. To assess this interpretation further, in the next experiment we tested the 4 subjects with even greater perceptual contrasts following a transformation from continuous to discontinuous quantities.

Experiment 5

The previous experiments have examined how different containers' shapes and various quantities of liquid might affect subjects' pointing toward the greater of two quantities following a transformation. However, in all cases subjects were exposed to a one-container-to-one-container (continuous) transformation. In the present experiment we investigated the effect of a transformation from continuous to discontinuous quantities in which the quantity presented in one container is transferred into several. Hence, this transformation entailed both liquid transference and the splitting of one quantity into multiple quantities. Such transformation corresponds to the third test of liquid conservation used by Piaget and Inhelder (1941) in their original study of children's achievement of concrete operations.

Method

Subjects. The subjects were the same as in Experiment 1.

Apparatus. In this experiment all containers used were of the same type. We used a set of glass cups used in the previous study (10 cm in height × 7.5 cm in diameter; see Figure 1) and two transparent trays. Cups were placed in groups of one, three, or six at the center of each tray and displayed on the same platform used in previous experiments. We tested subjects with 60-ml and 90-ml quantities of juice.

Procedure. The experimenter followed the same steps as in Experiment 4. A first set of two cups was used for the first transformation followed by the subject's first choice. In a second transformation, the experimenter transferred the contents of one container into one other identical container and the contents of the other container into several identical containers. This second transformation was followed by the subject's second choice, after which the experimenter offered the contents of the cup(s) for drinking without any further transfer. If subjects pointed toward a tray containing multiple cups, the experimenter offered the contents of each of the cups in succession. This method was preferred to pouring back the contents of each cup into the original cup to avoid cuing subjects about the invariance of the transformation. To habituate subjects to drinking from multiple cups, prior to testing each animal was exposed 5–10 times to a set of filled cups grouped together on a tray. After pointing toward the group of cups, the subject was rewarded with the contents of all the cups in succession.

As illustrated in Figure 5, we administered four different tests. In Test A, the first choice was between 60 ml and 90 ml in two identical cups, followed by the second choice between the 90-ml quantity poured into one cup and the 60-ml quantity divided into three containers with approximately 20 ml each. In Test B, the first choice was the same as in Test A, followed by the second choice between the 90-ml quantity poured into one container and the 60-ml quantity divided into six containers with about 10 ml each. In Test C, the first choice was the same as in Test A, followed by the second choice between 90 ml divided equally into three containers and 60 ml poured into one single container, whereas in Test D the second choice was between 90 ml divided equally into six containers and 60 ml poured into one container. Note that compared with the other experiments, in all tests, the second transformation from continuous to discontinuous quantities added perceptual contrast, with subjects having to combine the number of cups and the liquids' level to conserve quantities.

In each of three separate sessions we presented 3 trials of each type of test a randomized fashion (for a total of 12 trials per test). Cup sets were counterbalanced across trials for location and quantity.

Results

Following the first transformation, all subjects but one (Tiram) chose systematically the largest quantity (binomial tests: $ps < .05$ in all cases, $n = 12$). Again, these results confirmed that the majority of subjects tended to choose systematically the largest of two liquid quantities contained in identical cups. Following the second transformation, there were marked individual differences (see Figure 5).

Chantek pointed systematically to the largest quantity when the smallest quantity was transformed into multiple containers (Tests A and B; binomial tests: $ps < .01$ in both cases, $n = 12$). However, he tended to point systematically to the smallest quantity when the largest was divided (Tests C and D). Compared to Chantek, Tiram showed the exact opposite pattern of response, pointing systematically to the smallest quantity when it was transformed into multiple containers (Tests A and B; binomial tests: $ps < .05$ in both

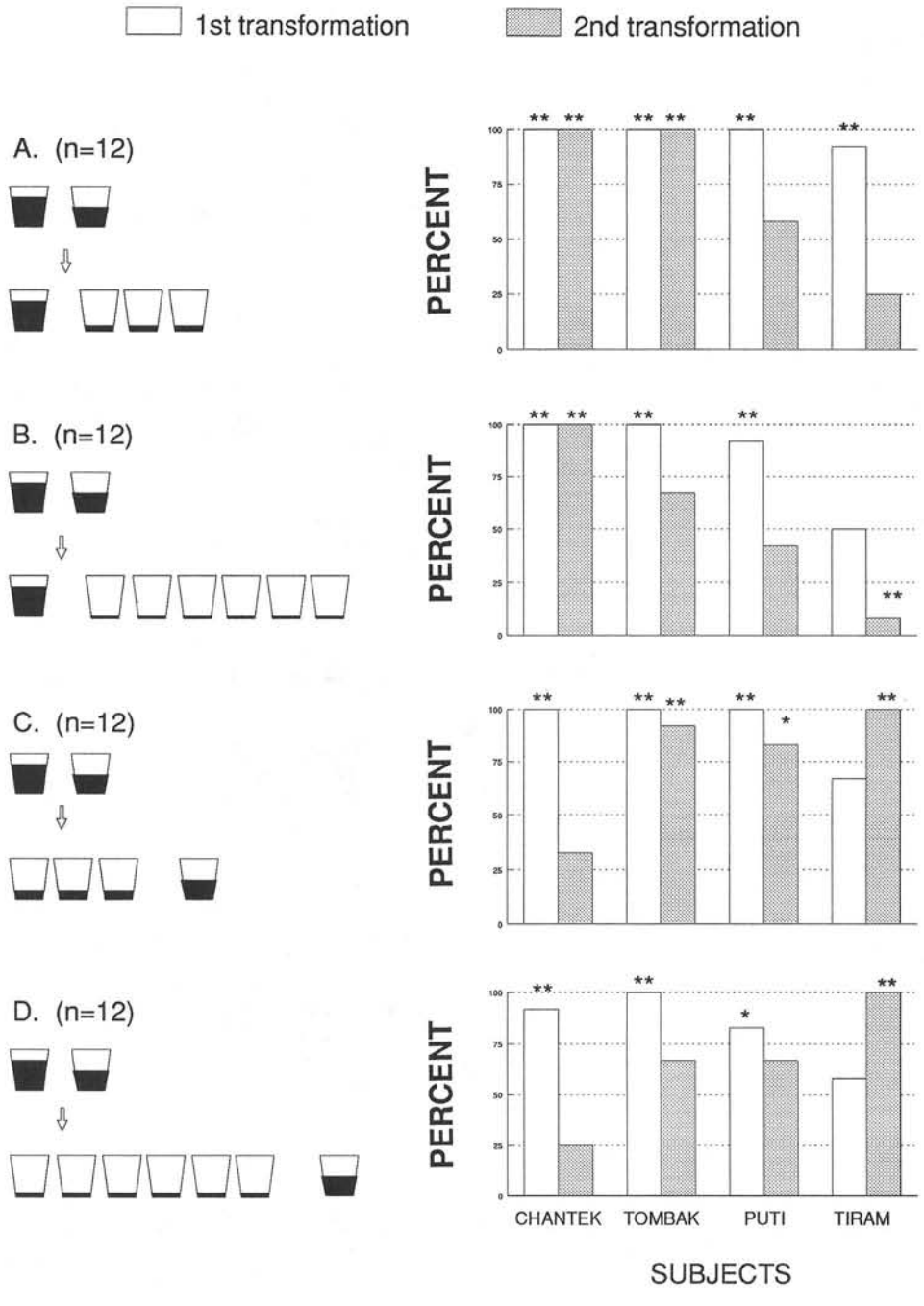

Figure 5. Percentage of trials on which subjects selected the container with the largest quantity of liquid after the first and second transformations. Glass cups were used, and liquid quantities were 60 ml and 90 ml. $*p < .05$. $**p < .01$.

cases, $n = 12$). However, he pointed systematically to the largest quantity when it was divided into multiple containers (Tests C and D; binomial tests: $ps < .02$ in both cases, $n = 12$).

Puti showed a pattern of response similar to Tiram, but less accentuated. In Test C she systematically chose the largest quantity when it was divided into three containers and tended to do the same when it was divided into six containers (Test D). This pattern of choice became more apparent after pooling together the data from Tests A and B and Tests C and D. Puti showed a significant preference for the largest quantity when it was divided into several containers (binomial test: $p < .05$, $n = 12$), but failed to show such preference when the quantity divided was the smallest

one (binomial test: *ns*, $n = 12$). Tombak showed a systematic choice toward the largest quantity in those tests involving a transformation from one to three containers only (Tests A and C; binomial tests: $ps < .02$ in both cases, $n = 12$).

Taken together, and in contrast to the other experiments, none of the subjects chose systematically the largest quantity across tests. Following the second transformation, 3 subjects chose the largest quantity in two of the four tests, the 4th subject in only one of the tests. In contrast, subjects were much more consistent following the first transformation, 3 out of 4 subjects choosing systematically the largest quantity on all test trials.

To assess the distribution of errors over time, we compared the number of errors during the first block of 6 trials with the second block of 6 trials after pooling the data from Tests A through D (see Figure 5). Thus, each block of trials represents a total of 24 trials (6 trials × 4 tests). No significant differences between blocks of trials (see Figure 5) were found for any of the 4 subjects (Puti: 9, 9; Tiram: 9, 11; Chantek: 11, 6; and Tombak: 5, 4 for Blocks 1 and 2, respectively; binomial tests not significant in all four cases). A more detailed analysis of the distribution of errors within the first block of trials did not reveal any evidence of trial-and-error learning. Errors were evenly distributed across the first two 6-trial blocks of the four tests (Puti: 3, 6; Tiram: 4, 5; Chantek: 6, 5; and Tombak: 3, 2 for Blocks 1 and 2, respectively; binomial tests not significant for all 4 subjects). Overall, these results indicate no evidence of trial-and-error learning.

Discussion

Compared with our previous experiments, we obtained a strikingly different pattern of results in this fifth experiment. The second transformation from continuous to discontinuous quantities led to mixed success in pointing to the largest of two volumes. In particular, it appears that subjects fell back into various perceptual strategies that do not support liquid conservation in the sense of a notion based on logical necessity. Our results suggest that for some subjects, their choice toward the largest of two volumes was based on the larger number of containers, irrespective of the actual amount of liquid they contained (i.e., Tiram and Puti). In sharp contrast, 1 subject (Chantek) chose the single container displaying the highest liquid level, irrespective of the multiplicity of containers with lower liquid levels. As for the 4th subject (Tombak), he showed a mixture of both strategies and was not systematic in his choice. As in Experiment 4, Tombak failed to choose the largest quantity when the perceptual contrast between the two possible choice items was increased (e.g., contrast between one continuous quantity vs. three discrete quantities, or one vs. six).

Overall, the results of the present experiment indicate that what appeared as evidence supporting conservation in Experiments 1, 3, and 4 has limitations and is not based on any logical necessity, as all 4 animals failed to be systematically successful in the context of a transformation from continuous to discontinuous quantities. Although the explanation based on different perceptual strategies such as height of the liquid or number of glasses offers a satisfactory explanation of the data, it is conceivable that orangutans used different criteria to make their choice. The most obvious alternative is that orangutans might have simply preferred to drink from a smaller or larger number of containers regardless of the quantity of liquid contained in them. This explanation seems unlikely, however, because it would represent bypassing the incentive provided by the amount of liquid, which, as previous experiments have demonstrated, represents a powerful force directing their choices.

Experiment 6

For purposes of direct comparison, we tested human children ages 6–8 years in the same conservation tasks, using an analogous procedure and identical material.

Method

Participants. Ten (4 girls and 6 boys) 6–8-year-old middle-class Spanish children recruited from a regular public school in Barcelona, Catalunya, Spain participated in this experiment.

Apparatus. The same cups and quantities of liquid as those used in the various experiments with orangutans were used in this experiment.

Procedure. We replicated the procedural steps of each of the four experiments with orangutans. However, children were engaged in a pretend questioning, with no drinking of the liquid following their choices. Previous to and following a particular liquid transformation performed by the experimenter, the child was asked to "point to the cup that you would choose to drink if you were very, very thirsty." Children were also interviewed on some trials to investigate their reasoning strategies behind their choices.

In the course of two sessions conducted over 2 successive days and lasting approximately 30 min each, each child was tested on all test items of the four experiments conducted with the orangutans. However, each child was presented with only 2 trials for each test item, for a total of 28 trials. In each test session there were seven different test items (total of 14 trials) that were randomized. Session 1 corresponded to the tests performed with orangutans in Experiments 1 and 3, and Session 2 corresponded to those performed in Experiments 4 and 5. Cup location and liquid quantity were counterbalanced across trials.

Because children had only two trials per test, the scoring procedure was different compared with the one used with orangutans. We assessed passing or failing on both trials for each test item. Children passed a test item if they chose the largest quantity on both trials. Conversely, they failed a test item if they chose the smallest quantity on both trials. When they chose the largest quantity on one of the two trials only, their choice was classified as inconclusive. Therefore, results were analyzed relative to three categories of performance: pass, fail, and inconclusive. Furthermore, to compare children's performance with the performance of the orangutans, we grouped the results by the test items corresponding to each of the four experiments. For this analysis, we considered that a child passed an experiment when he or she

passed all test items. Conversely, children were considered to have failed a given experiment if they did not pass any of the corresponding test items. The performance of children who passed only a few test items of a particular experiment was characterized as inconclusive.

Results

Table 1 summarizes the results of children and how they compare with those obtained with the group of orangutans. Three out of 10 children showed no failures in any of the experiments, two of which were systematically successful (Subjects S1 and S2). Three other children failed systematically in all experiments, and 4 others succeeded in some experiments only. The pattern of performance of some of these children who did not show conservation closely resembled that observed in the group of orangutans. In this regard, the strategies used to solve the experiment dealing with discontinuous quantities by children who showed no evidence of conservation deserves special attention. All children except 1 were using strategies that were also used by orangutans. In particular, 4 children based their choice on the number of cups available, whereas 1 child used height of the liquid as a basis.

Verbal justification provided by children regarding their choices showed that children did not show conservation; they tended to justify their choices on the basis of perceptual cues such as the height of the liquid or the number of containers available. In contrast, children who showed evidence of conservation justified their choices based on several strategies described by Piaget and Inhelder (1941) such as compensation (e.g., it is shorter, but it is also wider), reversibility (e.g., if you add all the glasses, there is more), or identity (e.g., there was less before).

Discussion

Two of the 10 children tested revealed robust conservation of quantities, clearly indicating that their performance was based on a different level of cognitive competence compared with the group of orangutans and the rest of the children. This finding is further supported by the verbal justifications provided by these children, who showed that their choices were not merely based on perceptual information. Nevertheless, the majority of children revealed a performance comparable with (or even lower than) that of the orangutans. Unlike orangutans, however, children who showed no evidence of conservation did not show a systematic breakdown of their performance in the context of a transformation from continuous to discontinuous quantities (Experiment 5). Most 7–8-year-old children were simply limited in their expression of conservation, as their successful performance appeared to depend on low perceptual contrasts between the tests items. When confronted with higher contrasts provided by the situation, they appear to fall back on a reasoning deprived of logical necessity (preoperational reasoning according to Piaget, 1955). Overall, this last experiment reveals that a majority of 7–8-year-old human children resembled orangutans in their inability to track the greater of two quantities in the context of various transformations.

General Discussion

Do orangutans show evidence of conservation and how do they compare with humans? Most of the orangutans showed signs of conservation during Experiments 1, 3, and

Table 1
Summary of the Results Obtained by Human Children and Orangutans in the Four Experiments on Conservation and the Hypothesized Strategy Used for Solving Experiment 4

Subject	Age (years)	Experiment No. 1	2	3	4	Strategy for Experiment 4
Humans						
S1	7.1	P	P	P	P	Identity and reversibility
S2	8.8	P	P	P	P	Reversibility and compensation
S3	7.2	P	I	I	P	Reversibility
S4	7.9	P	P	P	F	Height of liquid
S5	6.6	P	P	F	F	Number of cups
S6	7.8	I	P	F	F	Number of cups
S7	7.9	F	F	F	P	Compensation
S8	7.4	I	F	F	F	Unknown
S9	8.2	F	F	F	F	Number of cups
S10	8.4	F	F	F	F	Number of cups
Orangutans						
Chantek	16	P	P	P	F	Height of liquid
Tiram	6	P	P	P	F	Number of cups
Puti	12	F	P	P	F	Number of cups
Tombak	11	P	P	F	F	Number of cups and height of liquid

Note. P = pass; I = inconclusive; F = fail.

4, mainly when the outcome of the liquids' transformation produced a low perceptual contrast between the two containers. Most errors in these experiments were associated with transformations that produced an increase in perceptual contrast (e.g., Experiment 4, Test C). Interestingly, results of Experiment 5 revealed noticeable differences in strategies among subjects to solve the problem of continuous to discontinuous transformations. However, none of the expressed strategies led any of the orangutans to choose systematically the largest of the two quantities. Thus, the present study indicates that if orangutans show signs of an ability to track the larger of two quantities following a transformation, this ability is not context free. Hence, orangutans did not show evidence of conservation in the strict sense proposed by Piaget (1955), which implies logical necessity and an absolute independence from the perceptual context. The orangutans showed pseudoconservation in the context of relatively simple situations with low perceptual contrasts that did not involve discontinuous quantities. Paradoxically, their lack of conservation in more complex and error-prone perceptual contexts reveals that they are remarkably creative. In particular, orangutans are active problem solvers, using a variety of strategies to solve novel problems (i.e., basing their choice either on the liquid's level or on the number of containers). This creativity appears to be of a level comparable to most 7–8-year-old children, the difference being that children will eventually develop purely logical (operational) reasoning.

The results obtained in the experiments that did not involve transformations from continuous to discontinuous quantities are analogous to the observations reported by Woodruff et al. (1978) and Muncer (1983) with two chimpanzees. Within the context of a comparison between continuous quantities, orangutans, like chimpanzees, demonstrate some conservation. However, because this competence does not hold in the context of a transformation from continuous to discontinuous quantities, this conservation does not appear to rest on a logical inference. If orangutans, and maybe chimpanzees, do not conserve liquid quantities on the basis of logical reasoning, then how do they succeed in tracking quantities in conditions in which the transformation is from one container to another? There are at least three possibilities. One possibility is that orangutans attend to the actual pouring of the liquid from one container to another, perceiving the larger of two quantities on the basis of auditory and visual cues specifying the timing and amount of the liquid transfer. Experiment 2 was designed to test this possibility. Its results demonstrate that subjects did not use these cues to choose the largest of the two quantities. A second possibility is that orangutans are expert perceivers and are remarkably accurate in directly detecting the largest of two volumes. This alternative has been tested and discounted by both Woodruff et al. (1978) and Muncer (1983) in chimpanzees. Thus, it is likely that this possibility may be discounted in orangutans as well. A third possibility is that once the animal detects which container contains the largest quantity, it tracks this quantity in the course of the various transformations. Note that this last possibility has not been systematically tested and deserves further exploration. From an evolutionary perspective, it seems appropriate for animals to have developed sophisticated perceptual strategies to track the largest quantity of food in a choice situation (see Gust, 1989).

Further research is needed to understand the origins of the orangutans' pseudoconservation as well as the determinants and nature of their ability to come up with different solutions to solve novel problems. In particular, future studies on conservation should adopt a developmental perspective to capture and compare the emergence of this competence across species, in the way Antinucci (1989) has studied sensorimotor development in different species of primates. Finally, considering the interindividual differences reported for these groups of 4 orangutans, future research should consider other variables such as the rearing conditions and the amount of contact with humans as potential determinants of these differences (see Call & Tomasello, in press).

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