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Perceptual Strategies in the Estimation of Physical Quantities by Orangutans (*Pongo pygmaeus*)

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The perceptual strategies used by 4 orangutans (2 subadults, 2 adults) when choosing the larger of 2 volumes in a Piagetian conservation task were investigated. Three possible perceptual strategies were investigated: (a) direct perceptual estimation of the container's content independent of its shape, (b) use of the spatial and temporal cues provided by the pouring of liquid from one container to another, and (c) ability to initially identify the larger volume and track it across transformations disregarding misleading perceptual cues. Results indicated that the direct perceptual estimation strategy was the best candidate to explain the orangutan's systematic choice of the larger of 2 quantities.

The ability to perceive physical quantities and to track their invariance over time is considered a major landmark in the ontogeny of human cognition. In their pioneer work, Piaget and Inhelder (1941) established that by approximately 8 years of age (stage of concrete operations), the conservation of quantities is an integral part of the child's reasoning about physical transformations. In a comparative perspective, an important question is whether this developing competence is specifically human or might also be expressed in other species. It is conceivable that the use of representational and reasoning abilities may be beneficial to a number of species. For instance, in foraging situations, a number of animals are frequently confronted with the need to make choices between two or more food patches of unequal size (van Schaik, 1989; Wrangham, 1980). An ability to compare and decide between the larger of two food patches, regardless of their appearance and after they have been physically transformed, may prove to be quite advantageous.

In recent years, researchers have started to address this question by testing nonhuman primates in their ability to perceive differences in physical quantities and to track invariant aspects of physical transformations. Czerny and Thomas (1975) found that four squirrel monkeys (*Saimiri sciureus*) were able to provide accurate same–different judgments regarding pairs of identical glasses containing different volumes of liquid. With two individuals of this same species, Thomas and Peay (1976) also demonstrated an ability to make accurate same–different judgments regarding the length of rods used in the context of a length conservation task. Using a learning set paradigm, Pasnak (1979) reported similar results with two rhesus monkeys (*Macaca mulatta*). Working with an adult female chimpanzee ("Sarah," *Pan troglodytes*) trained to use plastic tokens symbolizing "same" or "different" judgments, Woodruff, Premack, and Kennel (1978) showed that this individual passed the Piagetian test of liquid and matter conservation but failed to show any conservation of number. Woodruff et al. concluded that this chimpanzee was able to infer the invariance of liquid and matter quantity following physical transformations, not simply basing her judgments on potentially deceiving perceptual cues. This interpretation is supported by the fact that Sarah did not judge accurately the two quantities following the transformation if she did not have the opportunity to explore the two quantities prior to the transformation. In addition, she correctly judged the relation between the two quantities (same vs. different) if some of the initial quantities were added or subtracted. However, the use of same–different tokens did not allow for a specification of which quantity was perceived as the larger and hence did not provide any information regarding the perceptual cues on which the animal based her judgments. Muncer (1983) reported that one of two juvenile chimpanzees demonstrated liquid and number conservation by selecting the larger of two quantities following physical transformations. This chimpanzee persisted in differentiating the larger of two quantities despite changes in perceptual appearance.

In a series of experiments, Call and Rochat (1996) recently investigated the capacity of four orangutans (*Pongo pygmaeus*) to conserve quantities of liquid following various transformations of increasing complexity. Subjects were trained to point manually to request food. On the basis of the fact that all animals systematically requested the larger of two quantities of valued food, this propensity was used to test their persistence in tracking the larger of two quantities following physical transformations. Call and Rochat found

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that the majority of the tested orangutans persisted in choosing above chance the larger quantity of liquid following a transformation from one container to another container with a different shape (i.e., low perceptual contrast). However, no subject demonstrated evidence of liquid conservation following a transformation from one container to multiple containers of identical shape (i.e., high perceptual contrast). Analysis of individual performances indicated that each subject adopted a variety of strategies, often demonstrating flexibility in using different strategies in the course of testing, such as the liquid's height in the new pair of containers following the transformation, its relative width, or the number of final containers in the case of a transformation from continuous to discontinuous quantities. In comparing these results with a group of 6- to 8-year-old human children, the authors concluded that the orangutan's performance was equivalent to what Piaget and Inhelder (1941) described as the intermediary stage of liquid conservation. Their performance corresponded to pseudoconservation in the context of relatively simple situations in which there was a low perceptual contrast between pairs of containers. Rather than the expression of an inference based on logical necessity, the performance of orangutans appeared to be linked to a sophisticated perceptual analysis that remained context dependent.

In their discussion, Call and Rochat (1996) speculated on three possible perceptual strategies that might be used by orangutans to succeed in conservation tasks involving (simple) transformations from continuous to continuous quantities. One possibility is that orangutans were accurate in directly perceiving the larger of two liquid volumes, independently of either the actual transformation or variations in containers' shape. Another possibility is that orangutans attended to the actual pouring of the liquid from one container to another, persisting in perceiving the larger of two quantities on the basis of auditory and visual cues specifying the timing and amount of liquid transfer. Finally, a third possibility is that subjects detected the larger of two quantities and then tracked this quantity in the course of various transformations. The present research was aimed at further exploring these perceptual strategies that might underlie orangutan pseudoconservation. In the present study we report three experiments, each designed to test the ability of orangutans to choose the larger of two quantities based on one of the perceptual strategies outlined above. The general aim of the research was twofold: (a) to explore the perceptual strategies underlying orangutans' ability to conserve physical quantities following simple transformations and (b) to gauge orangutans' perceptual sophistication in the context of a problem-solving situation.

Experiment 1

This first experiment was aimed at investigating whether orangutans are capable of directly perceiving the larger of two liquid volumes, without any prior transformation cues. In particular, we investigated orangutans' relative dependence on cues pertaining exclusively to the liquid's height and width in the container when choosing the larger of two liquid volumes. Pairs of containers, either identical or different in shape, containing unequal quantities of liquid, were directly presented to the orangutan for a choice. No pouring of the liquid in the containers was performed in front of the subject, canceling out any perceptual cues from such transformation. In order for the animals to succeed in choosing systematically the larger of the two quantities, they had to discriminate this quantity on the basis of perceptual information that combined height and width of the liquid in the container, regardless of its shape. Such perception would be direct as it pertains to a static presentation of the pairs of containers, without any previous dynamic cues provided to the animal.

Method

Subjects. Four orangutans (*Pongo pygmaeus*) housed at the Yerkes Primate Center and the Memphis Zoo served as subjects (see Table 1 for subject information). They included 1 subadult male ("Tombak") and 1 subadult female ("Puti"), both nursery reared, and 2 adult males ("Teriang" and "Chantek"). Teriang was mother reared; Chantek was mother reared until 9 months of age, at which point he was transferred for 8 years to the University of Tennessee at Chattanooga where he became part of a sign-language and cognitive development project (see Miles, 1990, 1994, for additional information). All orangutans except Teriang had received conservation testing prior to this study (Call & Rochat, 1996).

All subjects except Teriang were housed in pairs. Chantek was individually tested in the presence of his cagemate (who did not participate in the present study), while Puti and Tombak were separated during testing. Housing at the Yerkes Primate Center and the Memphis Zoo had an indoor and outdoor area. Testing was conducted in the indoor areas of the subjects' enclosures. Subjects were fed twice a day on a diet of fruit, vegetables, and monkey chow. Water was available ad libitum, and subjects were not food deprived during testing.

Apparatus. We used various pairs of identical or different containers with either equal or unequal quantities of fruit juice mixed with 50% water. These types of drinks are commonly used in enrichment procedures for orangutans. Two different sets of transparent containers that had been used in our previous study were used in the current tests (Call & Rochat, 1996). The first set (the Cup set) consisted of two disposable plastic cups with bases and stems. One was an inverted cone ("champagne cup") with a height from top to bottom of 22.5 cm, a top diameter of 6 cm, and 180 ml of total capacity. The other was a cylinder ("wine cup") with a height of 10 cm, a diameter of 7.5 cm, and a total capacity of 270 ml. The second set (the Tube set) consisted of one plastic cup

Table 1
Subjects Included in the Study

Subject	Age (years)	Gender	Location	Experimental history
Chantek	18	M	Yerkes	1, 2, 3, 4, 5
Tombak	13	M	Memphis Zoo	1, 2, 4
Puti	14	F	Memphis Zoo	1, 2, 3, 4
Teriang	23	M	Yerkes	1, 4

Note. M = male; F = female; 1 = social learning; 2 = conservation; 3 = gestural communication; 4 = tool use; 5 = sign language.

("glass cup") with a height from top to bottom of 10 cm, a top diameter of 7 cm, and 320 ml of total capacity. The other container consisted of a narrow test tube ("tube cup") 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 (see Figures 1 and 2).

The same quantity of liquid poured into each of the containers in each of the sets provided a marked perceptual contrast in height. In general, the Tube set provided greater contrast compared to the Cup set. The experimenter presented the containers on the outside of the cage on a wooden platform (70 × 25 cm) raised 30 cm above the ground.

Procedure. Prior to actual testing, all subjects had been trained to request food or drinks by pointing with either one of their hands. Subjects used two basic styles of pointing. Puti and Tombak pointed by sticking all their fingers in one hand through the cage, whereas Chantek pointed with his index finger. Teriang displayed both pointing styles. All orangutans kept their palm on a down or sideways orientation while pointing. Details regarding such training are provided in Call and Rochat (1996). In the current study, the experimenter placed a pair of containers, each already containing a predetermined quantity of liquid, close to one another (approximately 2 cm apart) and in front of the subject. Before proceeding further, the experimenter made sure that the subject was oriented towards and looking at the containers. Next, the experimenter moved each cup 50 cm apart and waited for the subject to point towards one of the cups. Following pointing, the experimenter gave the content of that container (regardless of whether or not it actually contained the larger quantity) to the subject by pouring it into his or her mouth through the cage fence. After the subject drank the juice, the experimenter removed the remaining cup from the platform and recorded 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 proceeded with the next presentation. Throughout testing, the experimenter wore a baseball cap with a long bill. At the time subjects selected one of the containers, the experimenter looked down at the center of the platform (where no container was placed) and maintained a neutral facial expression. In this way, most of the experimenter's face was not visible to the subjects, preventing him/her from obtaining inadvertent orientation cues.

There were two different testing phases depending on the set of containers used (see Table 2). During a pretest, a pair of identical containers (glass cup) with four different quantities of liquid (30, 45, 60, and 90 ml) were presented. This pretest was used to assess the propensity of subjects to choose the larger of the two quantities. We only used unequal quantities since our previous research (Call & Rochat, 1996, Experiment 1c) had shown that when presented with equal quantities in a pair of differently shaped containers, subjects did not show a bias for one particular type of container. Subjects received 12 trials with the larger volume counterbalanced for left–right position. Since Teriang had not been part of our previous study, he was given 72 additional trials to familiarize him with the testing procedure. Seventy-two trials provided Teriang with approximately the same amount of experience as the other 3 subjects after they had completed Experiment 1 of our previous study.

Following the pretest, either pairs of the Cup set or the Tube set were presented with various combinations of unequal liquid volumes (30, 45, 60, and 90 ml). As shown in Table 2, each set was presented with two different combinations of unequal quantities. The left or right position of both the larger quantity and the type of cup was counterbalanced across trials. For each set of containers (Cup or Tube) there were two types of contrast, depending on whether the container's shape perceptually accentuated or reduced the difference between the two volumes of liquid. In congruent trials (i.e., accentuated effect) the larger quantity was presented in the container whose shape accentuated the difference between the volumes (e.g., presenting the larger volume in the elongated tube and the smaller volume in the glass cup). In "incongruent trials" (i.e., diminished effect), the difference between the volumes was apparently diminished, with the larger volume presented in the container whose shape minimized the difference between the two

Figure 1. Orangutan pointing to the "glass cup." The "tube cup" is also shown on the left.

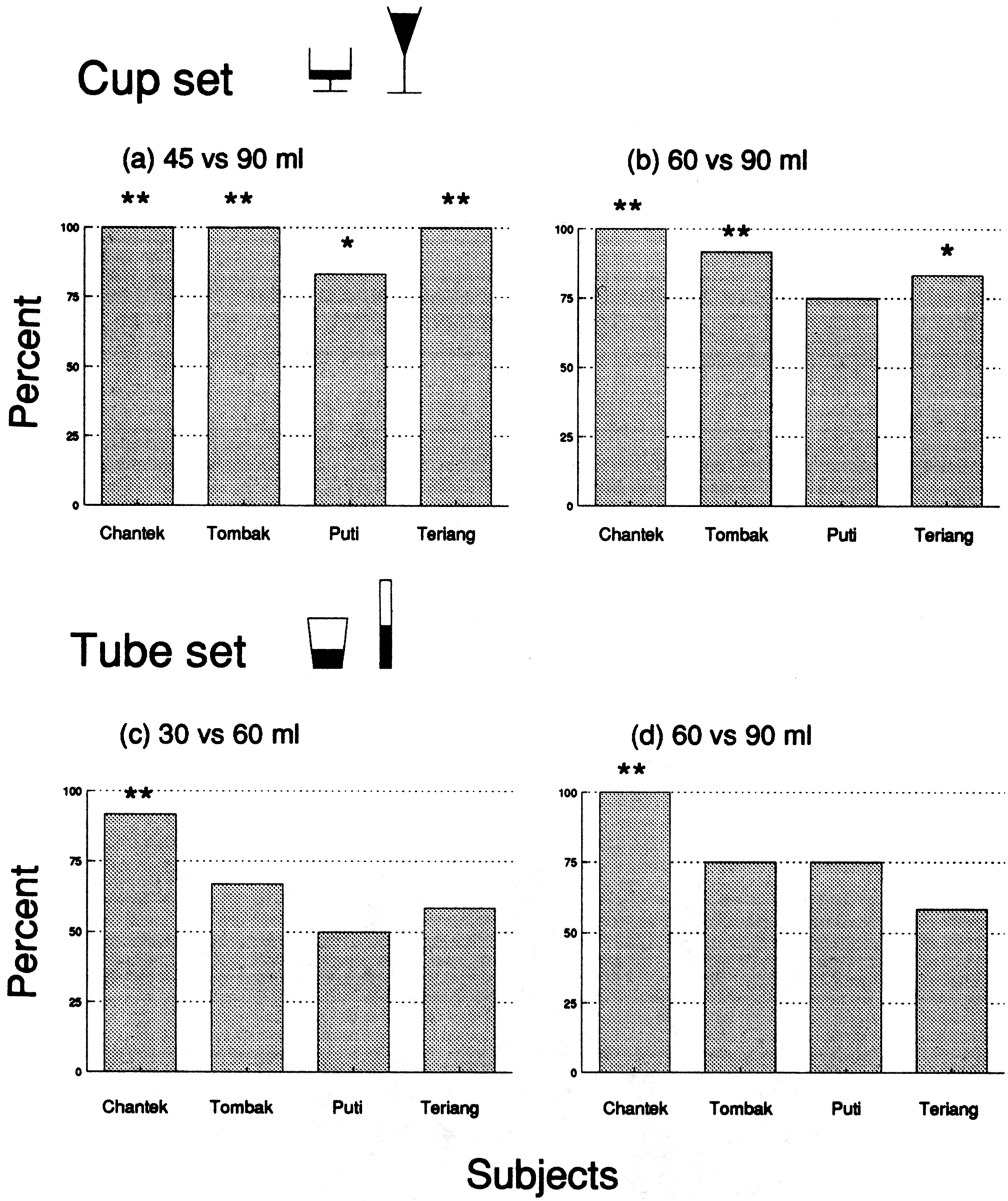

Figure 2. Percentage of trials in which subjects selected the larger volume of liquid as a function of container set and quantities being compared in Experiment 1. The Cup set was formed by the "wine cup" and the "champagne cup." The Tube set was formed by the "tube cup" and the "glass cup." $*p < .05$. $**p < .01$.

volumes (e.g., presenting the larger volume in the glass cup and the smaller volume in the tube). Each subject was tested in four sessions of approximately 30 min in which they were given 48 test trials presented in random order.

Results

As in the previous research (Call & Rochat, 1996), each of the 4 subjects chose systematically the larger of the two volumes during the pretest with values ranging from 92% to 100% of the trials (binomial test: $ps < .01$ in all cases). Because Teriang had been given less previous exposure to the choice procedure, he was given an extra set of 72 trials. These extra trials confirmed that his performance during this test was above chance selecting the larger volume in 75% of the trials (binomial test: $p < .01$).

During the test phase, all 4 subjects were above chance in choosing the larger of the two volumes of liquid overall (binomial tests: $ps < .01$ in all cases). Figure 3 shows the percentage of trials in which subjects chose the larger of the two volumes in congruent and incongruent trials. Although all subjects selected the larger volume more often in congruent trials compared to incongruent trials, this difference was not significant for any of the subjects (chi-square tests < 2.57, *ns,* in all cases). One subject (Puti), however, failed to choose above chance the larger of the two volumes during the congruent trials (but note that overall subjects received more congruent and incongruent trials).

Because the type of contrast between containers (congruent vs. incongruent) did not have a significant effect in the subjects' performance, we collapsed this variable for the following analyses. Figure 2 shows the percentages of trials in which subjects selected the larger volume of liquid as a function of container set and quantities being compared. In the Cup set trials only, all subjects chose above chance the larger volume in the 45- versus 90-ml comparison (binomial test: $ps < .05$ in all cases), while 3 out of the 4 subjects did so when 60 ml and 90 ml were compared (binomial test: $ps < .05$ in all cases). In contrast, results in the Tube set trials revealed that only one subject (Chantek) chose above chance the larger volume in both the 30- versus 60-ml comparison and the 60- versus 90-ml comparison (binomial tests: $ps < .01$ in both cases). The results obtained with this

Table 2
Experimental Phases, Type of Containers, Volumes, and Contrasts Used in Experiment 1

Phase	Container	Volume (ml)	Contrast
Pretest	glass:glass	30:60	congruent
	glass:glass	45:90	congruent
	glass:glass	60:90	congruent
Test			
Cup set	wine:champagne	45:90	congruent
	champagne:wine	45:90	incongruent
	wine:champagne	60:90	congruent
	champagne:wine	60:90	incongruent
Tube set	glass:tube	30:60	congruent
	tube:glass	30:60	incongruent
	tube:glass	60:90	incongruent

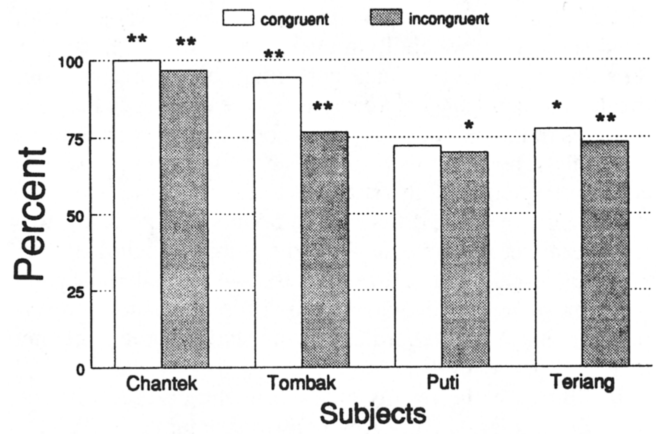

Figure 3. Percentage of trials in which subjects selected the larger volume of liquid in congruent and incongruent trials during Experiment 1. $^*p < .05$. $^{**}p < .01$.

particular subject indicated that neither the container set nor the quantities being compared had a significant effect on his performance. The other subjects were not above chance in either comparison in this set (binomial tests: *ns* in all cases).

Furthermore, when we compared the results obtained with the Cup or the Tube set using 60 versus 90 ml (the one comparison common to both sets), 2 of the subjects that selected the larger quantity above chance in the Cup set trials dropped to chance level in the Tube set trials. This result indicates that the contrast between the containers rather than the actual difference in volumes affected subjects' performance in choosing the larger of the two quantities.

A comparison of the number of errors during the first and the last block of 12 trials yielded no significant differences between blocks for any of the 4 subjects (first/last block: Chantek = 0/0, Tombak = 1/3, Puti = 4/3, Teriang = 4/5; binomial tests: *ns* in all four cases). A more detailed analysis of the distribution of errors within the first block of 12 trials conducted by dividing the data evenly into three blocks produced analogous results. Errors were uniformly distributed across block trials (1st/2nd/3rd block: Chantek = 0/0/0, Tombak = 0/1/0, Puti = 2/1/1, Teriang = 2/1/1). We also analyzed the error distribution within each experimental condition in which subjects were above chance (but not 100% correct, see Figure 2), hence affording the possibility of trial-and-error learning. Under these conditions, errors were uniformly distributed across block trials in all cases (1st/2nd block: Chantek = 0/1, Tombak = 0/1, Puti = 1/1, Teriang = 1/1). In summary, none of these post hoc analyses furnished any evidence for trial-and-error learning during the test.

Discussion

Overall, the results of Experiment 1 indicate that orangutans can estimate the larger of two volumes of liquid based on static perceptual cues. The 4 subjects demonstrated some ability to perceive directly the relative amount of liquid and, based on this perception, chose the larger of two volumes independently of the containers' shape. However, for 3 of the 4 subjects, it was only in the context of the Cup set that they showed above chance performance for presentations that both accentuated and diminished the difference between volumes in the pair of containers (congruent vs. incongruent test trials). Because this result was consistent for all pairs of compared quantities, the shape of the containers rather than the magnitude of the differential amounts of liquid appeared to determine the accuracy of the subjects' choice. Our previous research had also shown that when equal quantities were presented in containers of different shape, subjects made their choices regardless of the shape of the container (Call & Rochat, 1996).

In summary, the results of Experiment 1 suggest that in the context of relatively low contrast containers (i.e., Cup set), orangutans are good direct estimators of the global quantity of liquid. The question addressed in the next experiment is the extent to which the same orangutans can also use the dynamic cues of pouring as an index of liquid quantity.

Experiment 2

In the previous experiment, we eliminated any transformation cues (i.e., pouring) that might inform the subject about the amount of liquid in each container. Consequently, a systematic (above chance) choice of the larger volume had to be based on the combined detection of liquid height and width within a particular container. In the present experiment, we removed such static cues and presented the subject with a pair of opaque containers into which different quantities of liquid were successively poured in different ways. In this second experiment, a systematic (above chance) choice of the larger volume had to be based on transformation cues (i.e., only the timing of the transfer or perceived flow of the pouring). The question guiding this research was whether orangutans were able to detect and use this information to determine their choice of the larger quantity of liquid.

Method

Subjects. Subjects were the same as in Experiment 1.

Apparatus. We used two pairs of identical conical, opaque plastic cups 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) that were placed on top of each cup following the liquid transfer. These two pieces of cardboard prevented subjects from perceiving the liquid's height from above, following the transformation. Four different quantities of liquid were used: 30, 45, 60, and 90 ml.

Procedure. The experimenter placed one of the pairs of opaque containers on the platform (see Experiment 1) 5 cm apart and poured successively two predetermined quantities into each of the containers from another pair of opaque containers. Subjects could only see the actual pouring but not the content in the containers before or after the transfer occurred. The container whose liquid was transferred was maintained approximately 10 cm above the container on the platform. Following each transfer, the experimenter immediately covered the top of the filled container with a piece of cardboard. Once both containers were filled and covered, the experimenter moved them 50 cm apart, and waited for a pointing gesture towards one of the containers. Following pointing, the experimenter offered the contents of the chosen container to the subject by pouring it into his or her mouth.

The timing of the pouring (liquid transfer) into each of the containers was systematically manipulated in two experimental conditions (see Table 3). In the constant time condition, pouring time was constant (3 s), hence independent of the volume of liquid actually being transferred. In this condition, the only perceptual cue regarding quantity offered to the subject was the relative amount of liquid flow over the 3-s transfer: the larger the transferred liquid quantity was, the larger liquid flow during the transfer (e.g., 30 ml would produce a flow of 10 ml/s, whereas 60 ml would produce a 20 ml/s flow; see Table 3).

In the variable time condition, pouring time of the various liquid volumes was varied systematically in the following way: in congruent trials,[1] pouring time was directly related to the poured volume (approximately 10 ml/s). For instance, for a test comparing 30 and 60 ml, the experimenter spent 3 s pouring 30 ml and 6 s pouring 60 ml. Under these conditions, the pouring time (but not the flow) could be used to determine the container with the larger volume of liquid. In contrast, during the incongruent trials, the pouring time was inversely related to the poured volume. For example, for a test comparing 30 ml and 60 ml, the experimenter spent 6 s pouring 30 ml and 3 s pouring the 60 ml. Under these conditions, the flow (but not the pouring time) could be used to determine the container with the larger volume of liquid. For the three comparisons of liquid volume there were three corresponding differential flow ratios (see Table 3). Following each transfer of liquid, the experimenter covered the container on the platform with a cardboard piece and gave the subjects a choice as detailed above.

Pouring time was controlled by the experimenter using a reliable counting technique that was practiced and assessed prior to testing. The position of the larger quantity was counterbalanced for left–right location across trials and conditions. Overall, the experimenter conducted 66 trials per subject (18, 24, and 24 trials for the constant time, variable time congruent, and variable time incongruent conditions, respectively).

Results

Figure 4 presents the percentage of trials in which subjects selected the larger volume of liquid as a function of the pouring condition. Overall subjects showed a low accuracy in choosing the larger volume of liquid. Only one orangutan (Chantek) was able to choose above chance the larger quantity of liquid in the variable time incongruent condition (binomial test: $p < .01$). Note than in this test, the flow of liquid could be used as an indicator of quantity. In contrast, when the flow was kept constant (variable time congruent condition), he was unable to consistently select the larger volume of liquid.

When the different volumes were analyzed separately (see Figure 5), the results did not change substantially. Three of the subjects were unable to reliably select the larger quantity of liquid (binomial tests: *ns* in all three cases). In contrast, Chantek significantly selected the larger quantity in the variable time incongruent condition for the 30- versus 60-ml

[1] Note that the variable-congruent condition was the Experiment 2 of Call and Rochat (1996), and it is included here for purposes of comparison with the other experimental conditions.

Table 3
Experimental Conditions, Pouring Times, Volumes, and Flows Used in Experiment 2

Condition	Pouring time (s)	Volume (ml)	Flow (ml/s)
Constant time	3:3	30:60	10:20
	3:3	45:90	15:30
	3:3	60:90	20:30
Variable time			
Congruent test[a]	3:6	30:60	10:10
	5:9	45:90	10:10
	6:9	60:90	10:10
Incongruent test	6:3	30:60	05:20
	9:5	45:90	05:18
	9:6	60:90	07:15

[a]Same as Experiment 2 in Call and Rochat (1996).

comparison (binomial test: $p < .01$) but failed to do so in the other two quantity comparisons (binomial tests: *ns* in both cases). Interestingly, Chantek's accuracy seemed to decrease according to the difference between the flows of the two cups being compared. In other words, the smaller the difference between the flows was, the lower his accuracy in selecting the larger volume of liquid. In particular, he showed the greatest accuracy in selecting the larger quantity when comparing 5 ml/s with 20 ml/s (corresponding to 30 vs. 60 ml, see Table 3) but the lowest accuracy when comparing 6.7 ml/s with 15 ml/s (corresponding to 60 vs. 90 ml). The values for 5 ml/s versus 18 ml/s (corresponding to 45 vs. 90 ml) fell in between those two values. Furthermore, when the values obtained in the constant time test were added to those of the variable time test (incongruent condition), the relation between the difference between flows and choice accuracy still held. In particular, for differential flows of 8.3, 10, and 15 ml/s the percentage of correct responses was 62.5%, 66.6%, and 87.5% respectively.

A comparison of the number of errors during the first and the last block of 12 trials yielded no significant differences between blocks for any of the four subjects (first/last block: Chantek = 3/2, Tombak = 5/4, Puti = 5/6, Teriang = 6/6; binomial tests: *ns* in all four cases). A more detailed analysis of the distribution of errors within the first block of 12 trials conducted by dividing the data evenly into three blocks produced analogous results. Errors were uniformly distributed across block trials (1st/2nd/3rd block: Chantek = 0/2/1, Tombak = 2/2/1, Puti = 3/1/2, Teriang = 1/3/2). When error distribution was analyzed for the only condition in which a subject was above chance (i.e., Chantek in the variable time incongruent condition), the errors were evenly distributed across block trials (1st/2nd/3rd block: Chantek = 0/2/1). Again, these post hoc analyses did not provide any evidence for trial-and-error learning during the test.

Discussion

Overall, all subjects but one demonstrated a lack of systematic choice towards the larger quantity of liquid on the basis of pouring cues only. The majority of subjects did not pick up the perceptual information contained in the timing and flow of the pouring to make their choice of the larger of the two quantities. However, one subject (Chantek) did appear to detect and use pouring cues depending on the level of their contrast. When the flow difference reached 15 ml/s, Chantek did choose the larger quantity close to 90% of the time. In contrast, the duration of pouring was not associated with any accurate choices. Overall, it appears that compared to the static perceptual information of Experiment 1, the

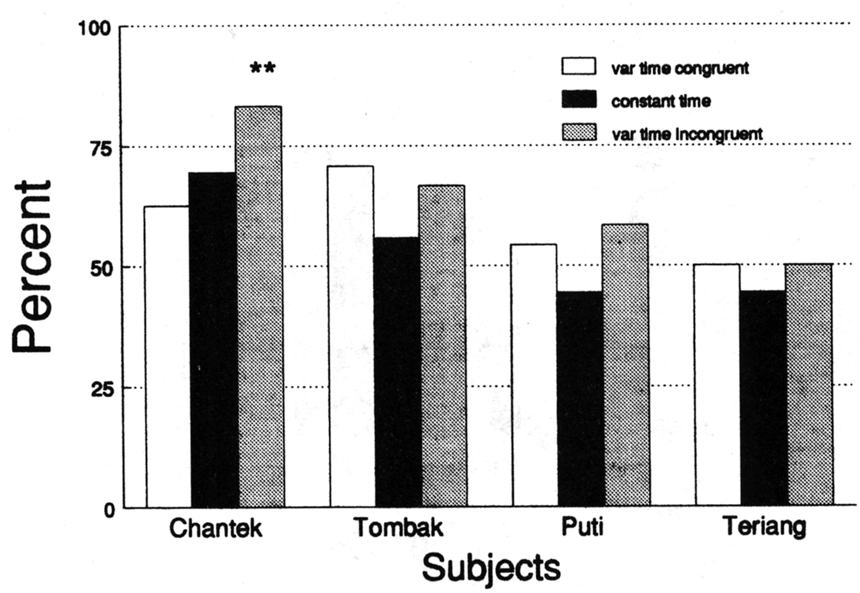

Figure 4. Percentage of trials in which subjects selected the larger volume of liquid as a function of pouring condition in Experiment 2. var = variable. $^{**}p < .01$.

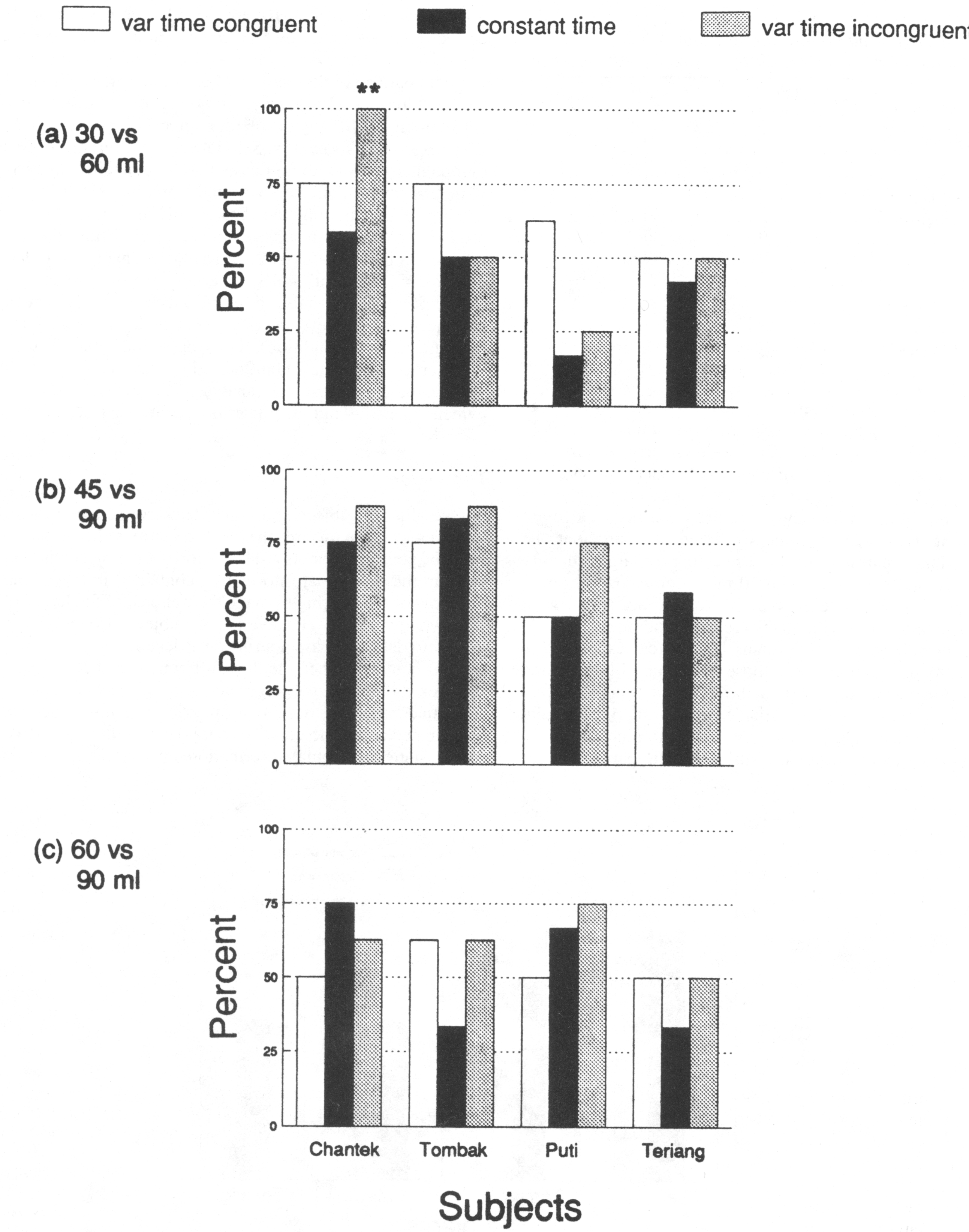

Figure 5. Percentage of trials in which subjects selected the larger volume of liquid as a function of pouring condition and quantities being compared in Experiment 2. var = variable. $^{**}p < .01$.

dynamic cues of pouring time and flow are not systematically picked up and used by orangutans. However, the exception of Chantek indicates that in particularly contrasted conditions orangutans might become potentially sensitive to flow information and use it in the determination of the larger volume of liquid.

One puzzling result is that Chantek discriminated in the variable time incongruent condition, but not in the constant time condition. The incongruent condition is arguably more difficult since the amount of liquid poured is in conflict with the amount of time spent in pouring the liquid (i.e., the less liquid available, the longer it takes, and vice versa). In contrast, the constant time condition is arguably easier than the former since there is no conflict between the amount of liquid poured and the pouring time. However, note that we, as humans, view the incongruent condition as more difficult because we perceive and use both the amount of time spent in pouring and the amount of liquid poured. An intriguing possibility is that Chantek may not perceive, or merely dismissed as irrelevant, the temporal information. If that were the case, from Chantek's point of view, there would be no incongruent result at all, and consequently, the variable time incongruent condition would not be more difficult than the constant time condition. On the contrary, the incongruent condition would be easier to solve because the flow difference is more accentuated than in the constant time condition (see Table 3).

Interestingly, the flow information that Chantek picked up corresponds to the perceived volume (i.e., volume of the actual liquid being transferred from one container to another) but not the time, hence apparently matching the perceptual ability underlying his performance observed in Experiment 1. This ability is also reminiscent of Chantek's performance in one of our previous experiments (Call & Rochat, 1996, Experiment 5) in which the liquid in single containers was transferred into groups of multiple containers. In that situation, Chantek selected the group of containers based on the liquid height, failing to compensate for the number of containers available. This compensation failure may be also analogous to Chantek's failure to take into consideration the temporal information in the present experiment. Taken together these results on compensation reinforce our initial assessment that orangutans may engage in pseudoconservation as opposed to conservation based on logical necessity when choosing between two liquid quantities.

Experiment 3

The third experiment addressed a third possible explanation for the successful performance in our original conservation tasks (Call & Rochat, 1996). This explanation is based on the idea that subjects may detect the larger of two quantities before any transformation is carried out and then merely track this quantity in the course of subsequent transformations. This tracking strategy would not use any perceptual cues provided by the liquid transfer itself or the liquid appearance after the transformation. If this were the case, participants would not show conservation in the strict sense but merely demonstrate tracking of a previously selected quantity without comparing the quantities after the transformation. In this experiment, we tested the animals' ability to use such a strategy by placing them in a situation where in order to choose successfully the larger of two quantities they had to track it. We addressed this question by presenting participants with quantities poured from clear into opaque containers that were then moved to different locations.

Method

Subjects. Subjects were the same as in Experiment 1.

Apparatus. We used the pair of transparent "glass cup" containers used in Experiment 1, the pair of opaque containers and circular pieces of cardboard used in Experiment 2, and the platform used in previous experiments.

Procedure. The experimenter placed a pair of containers the opacity of which depended on the experimental condition (see below) next to each other on the center of the platform in front of the subjects. Each container had been filled beforehand with either 30 or 60 ml of artificial fruit juice. Once the animal was oriented toward and apparently looking at the containers, the experimenter performed one of three possible manipulations corresponding to the three different experimental conditions.

In the clear–opaque (experimental) condition, the experimenter moved a pair of clear containers from the center of the platform to its opposite sides. Subjects selected one of the containers by pointing (first choice). Then, the experimenter moved the pair of clear containers to the center of the platform and poured their respective contents into two opaque containers, covering each of them with a piece of cardboard to prevent subjects from obtaining information about the amount of liquid available. Pouring time was approximately 1 s regardless of the poured quantity. Once the transfer from the clear to the opaque containers was completed, the experimenter removed the empty clear containers and moved the opaque containers to the opposite sides of the platform where the subject selected one container (second choice). In the opaque–opaque (control) condition, all steps were identical to the clear–opaque condition with the only exception that all the containers used were opaque (covered in all cases with a piece of cardboard to prevent the animal from perceiving the liquid from above). In the clear–clear (control) condition, all steps were identical to the clear–opaque condition with the only exception that all the containers used were clear. In the opaque–opaque condition we expected subjects to be unable to choose above chance the container with the larger quantity. In contrast, in the clear–clear condition we expect subjects to reliably choose the larger quantity. Finally, the clear–opaque condition constituted the test of tracking since in order to reliably select the larger quantity subjects had to remember its location and track its displacements on the platform.

For each of the three conditions, half of the trials were conducted with the pair of containers remaining on the same (left or right) side of the platform for the first and second choices (same location condition). For the other half, the experimenter switched the containers' side from left to right and right to left prior to the second choice (switched location condition). This variation permitted us to assess whether the animals were inclined to persist in choosing the container at the same location in which they had selected in their first choice, or, on the contrary, whether they would track the container they had previously selected as it moved from one side to another. Trials for the three experimental conditions were presented in random order. We used two quantities (30 and 60 ml) in all comparisons. We conducted a total of 36 trials per subject (12 trials per experimental condition).

Results

Figure 6 presents the percentage of trials in which participants selected the larger volume of liquid for each experimental condition in their first and second choices. In the opaque–opaque (control) condition, as expected none of the participants systematically selected the larger quantity of liquid either in their first or second choices (binomial tests: *ns* in all cases). In contrast, in the clear–clear (control) condition, all subjects (except Teriang in his first choice) selected the larger volume in their first and second choices (binomial tests: $ps < .01$ in all cases). In the clear–opaque (experimental) condition, all subjects except Teriang consistently selected the larger amount of liquid in their second choice (binomial tests: $ps < .05$ in all cases).

Figure 7 presents the percentage of trials in which subjects selected the same container in their first and second choices for each condition and depending on whether the containers remained on the same side or were switched (same vs. switched location) following the first choice. Figure 7a shows the results for the condition in which the containers remained at the same location for both choices. One subject (Teriang) did not show any systematic pattern in choosing the same container in both choices in any of the conditions (binomial tests: *ns* in all cases), whereas 2 other subjects (Tombak and Puti) systematically selected the same container (binomial tests: $ps < .05$ in all cases except in the clear–opaque condition for Puti). Chantek systematically selected the same container in the clear–opaque and clear–clear conditions (binomial tests: $ps < .05$ in both cases), but failed to do so in the opaque–opaque condition (binomial test: *ns*).

Figure 7b presents the percentage of trials in which subjects selected the same container in their first and second choices for each condition when the container was switched from its original location. Note that in this case, choosing the same container on both occasions (first and second) implied selecting different sides (left vs. right) since the containers had been switched from their original locations. Again, Teriang did not display any significant preference for either container in any condition (binomial tests: *ns* in all cases), whereas Chantek significantly selected the same container in both choices in the clear–opaque and clear–clear conditions (binomial tests: $ps < .05$ in both cases), but failed to do so in the opaque–opaque condition (binomial test: *ns*). In contrast, Tombak and Puti only selected systematically the same container in the clear–clear condition (binomial tests: $ps < .05$ in both cases).

A comparison of the number of errors (collapsing first and second choice) during the first and the last block of 12 trials yielded no significant differences between blocks for any of the 4 subjects (first/last block: Chantek = 4/7, Tombak = 5/3, Puti = 5/8, Teriang = 8/9; binomial tests: *ns* in all four cases). A more detailed analysis of the distribution of errors within the first block of 12 trials conducted by dividing the data evenly into three blocks produced comparable results. Errors were uniformly distributed across block trials (1st/2nd/3rd block: Chantek = 1/1/2, Tombak = 2/2/1, Puti = 3/0/2, Teriang = 4/1/3). Finally, we also analyzed the error distribution within the clear–opaque condition in which subjects were above chance (but not 100% correct, see Figure 6). In all cases, errors appeared to be uniformly distributed across block trials (1st/2nd block: Chantek = 1/2, Tombak = 0/2, Puti = 0/2). In summary, none of these post hoc analyses provided any evidence for trial-and-error learning during the test.

Discussion

In the clear–opaque condition, 3 out of the 4 animals demonstrated that they first detected the larger quantity and then remembered its corresponding location following the transfer into the opaque container. As a consequence, they showed some ability to choose the larger quantity when it was no longer directly perceivable. Given that some time elapsed since the containers' contents was visible, this result also confirms previous findings on the ability of orangutans to solve delayed response problems (Fischer & Kitchener, 1965; Harlow, Uehling, & Maslow, 1932). As would be predicted, in the opaque–opaque (control) condition the animals responded randomly for both choices. In contrast, all animals responded above chance in the clear–clear (control) condition.

Although all animals demonstrated some evidence of an ability to detect the larger quantity once transferred into an opaque container, it appears that this ability varied among the subjects. The analysis of the successful choices as a function of the two types of displacement prior to the second choice (i.e., same vs. switched location) revealed that only one animal (Chantek) showed some evidence of a persistence in successfully tracking the larger quantity following a displacement in the clear–opaque condition. Because the majority of subjects were successful in detecting the larger quantity in relation to both displacements in the clear–clear condition, it appears that only Chantek distinguished himself as capable of remembering where the larger quantity was situated on the display when (a) this quantity was not directly perceivable and (b) it did not return to the location where it was once directly perceived (switch condition). Chantek's performance is linked to a strategy that clearly implies greater cognitive ability than simply perceiving or remembering the location of the larger quantity, in particular memory of a permanent quantity that can be tracked in space. Such cognitive ability cannot be inferred from the performance of all the other animals in this third experiment, as their success depended on the location where the larger quantity was last seen. In a sense, their performance is analogous to the A-not-B error described by Piaget (1954) in which young infants persist in trying to retrieve a hidden object at the location where it was last seen, despite previous visible displacements. However, note that in the object permanence task in contrast to the task at hand, no comparison of quantities is required, and as a consequence the object permanence task may have a lower degree of complexity. This interpretation is corroborated by recent data that

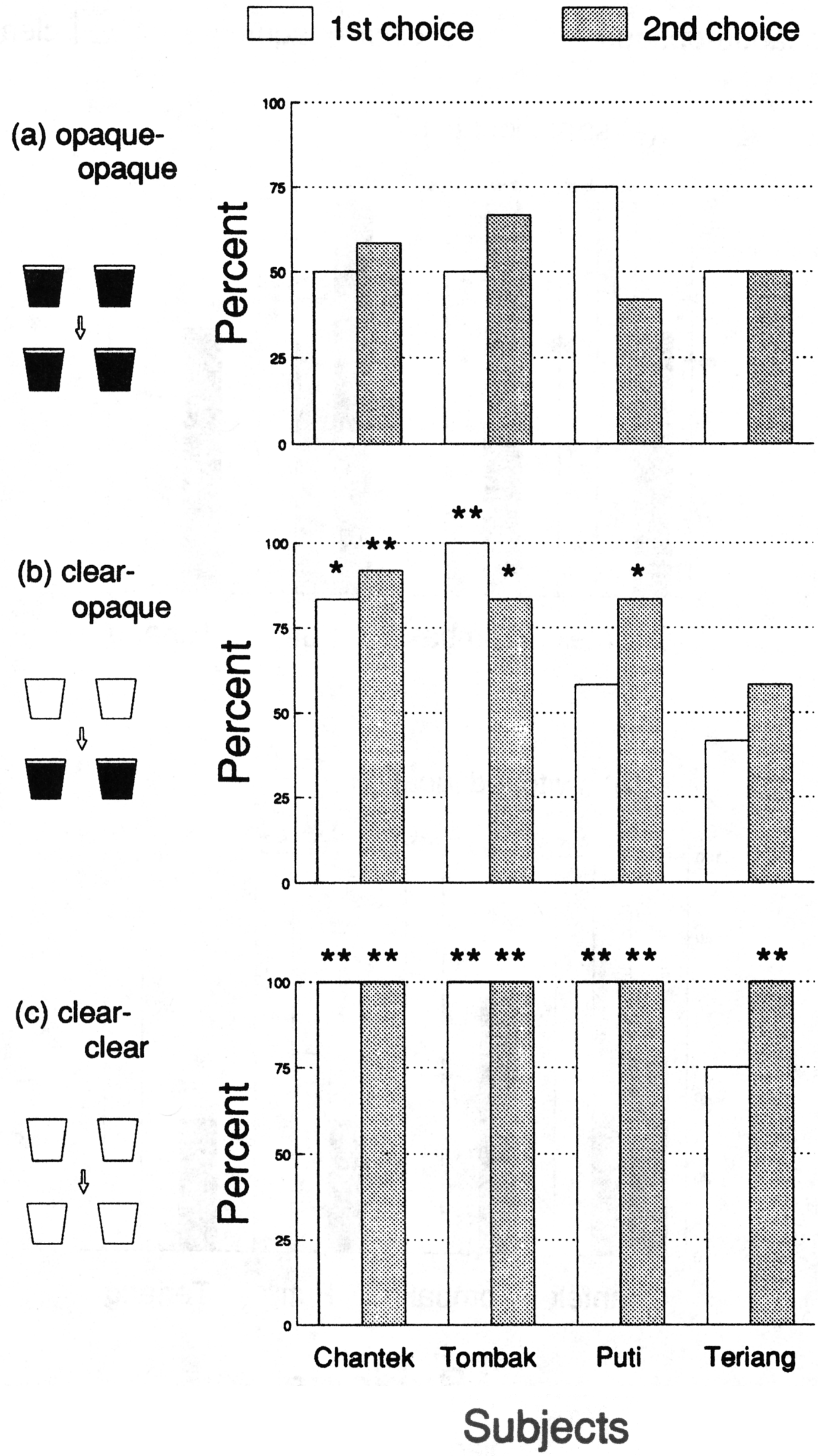

Figure 6. Percentage of trials in which subjects selected the larger volume of liquid in their first and second choices as a function of experimental condition in Experiment 3. $*p < .05$. $**p < .01$.

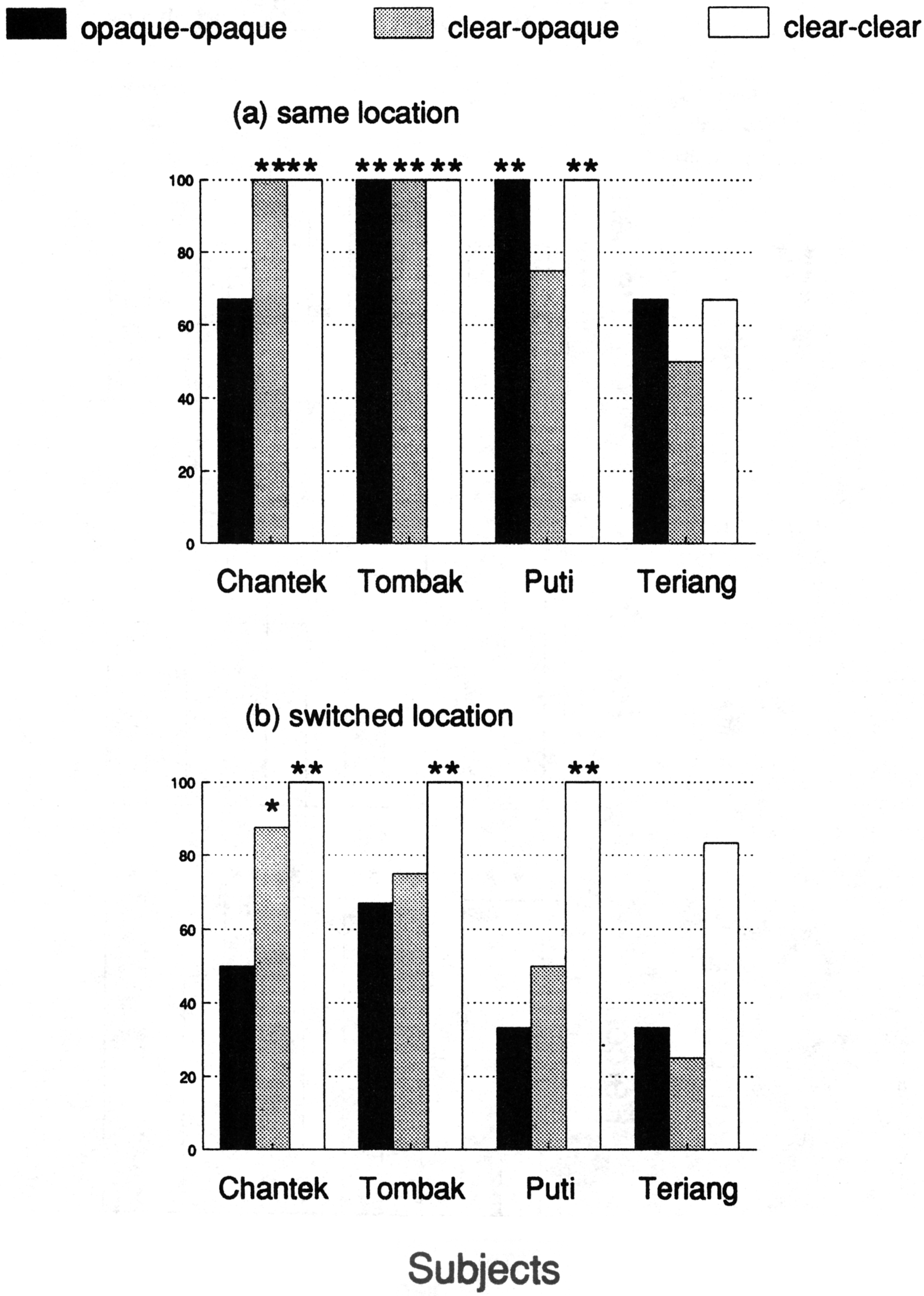

Figure 7. Percentage of trials in which subjects selected the same container during Choices 1 and 2 as a function of experimental condition and final location of the containers in Experiment 3. $^{*}p < .05$. $^{**}p < .01$.

indicate that orangutans did not commit the A-not-B error in a typical object permanence task (Call & Tomasello, 1996b). These later observations suggest that the orangutans' performance reported here does not depend exclusively on memory demands (e.g., Baillargeon, DeVos, & Graber, 1989).

General Discussion

In a previous study (Call & Rochat, 1996), we presented pairs of containers filled with unequal quantities of liquid to orangutans. In multiple experiments, orangutans consistently requested by pointing to the container with the larger amount of liquid. Following the general procedure, after an initial choice, the liquid was transferred into another pair of containers with different shapes. These shapes changed the initial appearance of the liquid in such a way that the container with the larger volume of liquid appeared to have less than the container with the smallest amount of liquid. This effect was obtained, for example, by transferring the larger volume of liquid into a short and wide container while pouring the smaller volume into a long and narrow container. Unlike most of the 6- to 8-year-old children tested in the same task, orangutans persisted in selecting the larger amount of liquid after the transformation despite any perceptually misleading appearance. However, because none of the orangutans demonstrated a systematic choice towards the larger quantity transferred into a collection of discrete small containers, we concluded that orangutans based their judgments on a perceptually based estimation rather than inferential reasoning and logical necessity.

In interpreting these results we speculated that there were three possible perceptual strategies that might underlie the successful performance or pseudoconservation observed in orangutans. The first strategy would be based on a direct, accurate perceptual estimation of the container's content independently of its shape (perceptual strategy). Accordingly, orangutans would be skilled, accurate estimators of physical quantities, regardless of their physical appearance. A second strategy would correspond to the attentional focus of the animal on the spatial and temporal characteristics of the actual transfer or pouring of liquid from one container to another (pouring strategy). In this case, perceptual information provided by the pouring itself would specify the transferred quantity. Finally, a third strategy (tracking strategy) would correspond to the initial detection of the larger quantity of liquid in a particular container and the tracking of this quantity across the transfer from container to container. Results of the present research indicated that the first (perceptual strategy) is the best candidate to account for the animals' systematic choice of the larger of two quantities reported in Call and Rochat's (1996) study. This is illustrated in Table 4, where the percentage of trials in which subjects selected the larger volume of liquid in each of the three conditions investigated (corresponding to three possible cues) are directly compared. In addition, Table 4 also contains the percentage of trials in which subjects selected the larger volume in our previous study (Call & Rochat, 1996) when all the cues were simultaneously available.

Table 4
Mean Percentage of Pointing Toward the Larger Quantity for Each Subject as a Function of the Type of Perceptual Cue Available

	Type of cue			
Subject	Perceptual[a]	Pouring[b]	Tracking[c]	All combined[d]
Chantek	97.9	62.5	87.5	100
Tombak	85.4	70.8	75.0	85.0
Puti	77.1	54.2	50.0	90.0
Teriang	75.0	50.0	25.0	Not tested

Note. Values in this table represent those conditions within each experiment whose procedure makes them comparable to the procedure followed in the Call and Rochat (1996) study.
[a]From Experiment 1. [b]From Experiment 2, variable time congruent condition. [c]From Experiment 3, clear–opaque condition. [d]From Call and Rochat (1996), Experiments 1, 2, 3, and 4.

Although we have indicated that cues obtained from the container's appearance are more salient for orangutans than cues obtained from the actual pouring of the liquid from one container into another, it is important to note that when only the pouring cues were available, these cues were provided successively rather than simultaneously. This absence of simultaneity might have added a memory load in the use of pouring cues to solve the problem. This additional load might account for the differences in performance observed between Experiment 1 (test of the perceptual strategy) and Experiment 2 (test of the pouring strategy). Note that the rationale for simultaneous or successive presentation in the present research was to replicate the procedure used in our previous study (Call & Rochat, 1996). Under the conditions specified in our previous study, it is clear that for orangutans the container's appearance is the most useful cue in deciding which one of two containers has the larger volume of liquid. An interesting question is whether orangutans would continue to use successfully the first strategy in the context of a successive rather than a simultaneous presentation of the containers. Future research should address such questions in order to provide much needed information on the limits and nature of orangutan cognition.

The results obtained in Experiment 1, which was designed to test the perceptual strategy hypothesis, are comparable to those obtained in previous studies where orangutans had all three sources of information available (perceptual, pouring, and tracking information). In contrast, when the perceptual cues were made unavailable to the orangutans, using opaque containers that left only either pouring or tracking information available to them, there is little evidence that they were able to select reliably the larger of the two volumes. However, one participant (Chantek) demonstrated some evidence of an ability to pick up and use pouring and tracking information, without using the appearance of the liquid in the containers. In these situations, Chantek persisted in choosing above chance the larger quantity, evidently picking up pouring information or tracking the larger quantity in its displacement. Chantek's unique performance is particularly interesting considering that among the four tested individuals, he was the one with a history of human enculturation, having been reared from 9 months of age by humans and treated by them as a human child (see Miles, 1990, 1994, for further details). Among other factors that remain to be elucidated, the exceptional perceptual and cognitive ability of Chantek needs to be considered in light of his unique rearing history. Future research should investigate further how human enculturation might be at the origins of some exceptional cognitive abilities demonstrated by apes (see Call & Tomasello, 1996a).

One basic feature that might differentiate Chantek from the other orangutans included in the present research is that he displayed a capacity to consider simultaneously multiple, redundant perceptual cues to solve a particular problem. In the task we studied, Chantek appeared not only to have merely perceived the differential quantity of liquid in each container, but also under certain contrasted conditions, appeared to have detected information pertaining to the pouring or tracking of the liquid. In general, and in contrast to the other participants, Chantek demonstrated flexibility in the use of different strategies to solve the problem, capitalizing appropriately on the available information. Research on gestural communication and tool use has shown that nonenculturated orangutans can use multiple ends to achieve a particular goal, and can do so flexibly (Bard, 1992; Call & Tomasello, 1994a, 1994b). However, most of the supporting evidence is linked to trial-and-error learning, the amount of such learning varying across studies and individuals. What is remarkable about Chantek in the present research is that his performance did not involve any trial-and-error learning opportunities, as he was never provided with any direct feedback on his performance. When Chantek performed correctly, he did so from the start, prior to any possible learning opportunity. Chantek's early rearing experience and close interaction with humans might account for his exceptional behavior. Human contact and prolonged interactions with human culture foster particular skills, and in particular a socialization of attention that is specifically human. This socialization of attention includes a receptivity to teaching and attentional scaffolding towards particular aspects of the environment (Bruner, 1972; Tomasello, Kruger, & Ratner, 1993). We propose that the scaffolding of attention, considered as the trademark of human enculturation, contributed to the greater perceptual and cognitive sophistication expressed by Chantek. Future research comparing problem-solving abilities by nonhuman primates with varying degrees of human enculturation should eventually provide further support to such a hypothesis.

In summary, the results of the present study lend support to our previous idea that orangutans rely on perceptual as opposed to inferential reasoning strategies to solve liquid conservation tasks. This reliance on perceptual information is supported by the combined findings of our past and present research. In our past research, in certain conditions where the apparent contrast between the quantities in their containers is increased, some subjects failed to point systematically to the larger quantity. Also, as shown in the last experiment of Call and Rochat (1996), when this contrast is further increased by transforming one quantity into multiple smaller quantities, all of the subjects (including Chantek) failed to continue to point above chance to the larger quantity. In the present research, the only participant apparently capable of using pouring information to select the larger volume of liquid, Chantek, did so only in situations where the contrast between flows was the most salient. Furthermore, the results presented here indicated that Chantek's exceptional use of pouring cues is based on perceptual information pertaining to the relative "thickness" of the liquid's flow, not its timing, which would potentially entail some reasoning in the successive comparisons of duration. These findings support the idea that even Chantek's problem solving was perceptually based, and not based on inferential reasoning or any of the logical necessity that qualifies conservation in the strict Piagetian sense.

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