

# How Orangutans (*Pongo pygmaeus*) Innovate for Water

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We report an observational field study that aimed to identify innovative processes in rehabilitant orangutans' (*Pongo pygmaeus*) water innovations on Kaja Island, Central Kalimantan, Indonesia. We tested for the basic model of innovating (make small changes to old behavior), 4 contributors (apply old behavior to new ends, accidents, independent working out, social cross-fertilization), development, and social rank. Focal observations of Kaja rehabilitants' behavior over 20 months yielded 18 probable innovations from among 44 water variants. We identified variants by function and behavioral grain, innovations by prevalence, and innovative processes by relations between innovations, other behaviors, and social encounters. Findings indicate innovating by small changes and some involvement of all 4 contributors; midrank orangutans were the most innovative; and rehabilitants' adolescent age profile, orphaning, and intense sociality probably enhanced innovativeness. Important complexities include: orangutan innovating may favor certain behavioral levels and narrowly defined similarities, and it may constitute a phase-like process involving a succession of changes and contributors. Discussion focuses on links with great ape cognition and parallels with innovating in humans and other nonhuman species.

*Keywords:* orangutan, great ape, innovation, innovative processes, creativity

We report an observational field study of innovative processes in orangutans based on water innovations in a rehabilitant population living in native habitat. Orangutans have been a recent focus of field studies on innovation, most of them focused on the innovations produced (Ramsey, Bastien, & van Schaik, 2007; Russon 2003b; Russon et al., 2009; van Schaik, van Noordwijk, &

Wich, 2006). The study of innovative processes is an important complement to the study of its products because the processes delimit the products (Hauser, 2003; Reader & Laland 2003). It has a long history in humans, as creativity (Finke, Ward, & Smith, 1996; Gabora, 2002; Simonton, 2003a), and in some nonhuman taxa (Marler, 1991; Slater & Lachlan, 2003) but the two bodies of work remain largely separate (Kaufman & Kaufman, 2004). Orangutans are a good choice for new studies of innovative processes. Intelligence correlates with innovativeness in several taxonomic groups, so orangutans' high intelligence suggests high innovative potential (Byrne, 2003; Lefebvre, Reader, & Sol, 2004; Marino et al., 2007; Reader, 2003). Their close biological relationship with humans suggests they could play a valuable role in linking the human and nonhuman work. We aimed to study orangutan innovative processes by inferring the behavioral pathways that led to their water innovations and the contributions of several key influences. Undertaking this study entailed adjusting existing methods to better identify innovations in orangutans and their innovative processes.

## Innovative Processes

Innovation's products and its generating processes are typically distinguished (Kaufman & Baer, 2006; Reader & Laland, 2003). Innovative products (hereafter, *innovations*) are the end results, that is, novel learned behaviors within a population that provide unusual and not immediately obvious solutions to a task (Reader & Laland, 2003). By implication, they should be relatively rare, task appropriate, and "underdetermined" by environmental, social, or maturational influences (Byrne, 2003; Greenberg, 2003; Kaufman & Kaufman, 2004; Ramsey et al., 2007; van Schaik et al., 2006).

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Innovative processes concern how individuals innovate, and are typically discussed in terms of factors that engender innovations in individuals (Reader & Laland, 2003). They range from intrinsic factors such as intelligence, learning capacity, novelty orientation, prior knowledge, and age to extrinsic factors such as severe or relaxed environmental pressures and social rank (Greenberg, 2003; Hauser, 2003; Kaufman & Kaufman, 2004; Kummer & Goodall, 1985; Lefebvre, Whittle, Lascaris, & Finkelstein, 1997; Reader & Laland 2003; Simonton, 2007).

The basic model of innovative processes, in humans and non-humans, is making small changes to existing behaviors (hereafter, *precursors*) because these are less risky and more likely to succeed than major changes; the novelty generated is then typically limited (Byrne, 2003; Kummer & Goodall, 1985; Reader & Laland, 2003; Simonton, 2003a, 2003b). Considerable evidence supports this model, for example, bird song (Marler, 1991; R. B. Payne, 1996; Slater & Lachlan, 2003), primate deception (Byrne, 2003), corvid tools (Hunt et al., 2007; Hunt & Gray, 2003), and human creativity (Simonton, 2003a; Ward, 2007). Thus task familiarity and existing behaviors fuel innovating, and actors with the broadest knowledge should be the most innovative because they have the most material for making new combinations (Gabora, 2002; Kummer & Goodall, 1985; Simonton 2003a; Sternberg, 2006).

We considered four events that contribute to innovating that are prominent in literatures on animal innovation and human creativity and detectable in behavior.

1. Applying preexisting expertise to new purposes generates novel function (Byrne, 2003; Kummer & Goodall, 1985); it is sometimes excluded for not generating new behavioral form.
2. Accidents can lead to co-occurrences of behaviors or events that are normally segregated, thereby sparking novel connections (Simonton, 2003a).
3. Novel behaviors may be worked out independently, including generating novel components and testing, practicing or refining them (Gabora, 2002; Simonton, 2003a). This may occur in unusual conditions and, for ecological innovations, when free of social distraction (Kummer & Goodall, 1985) so play may be involved (Burghardt, 2005).
4. Social cross-fertilization, that is, input from others' activities and shared or parallel behavior, can broaden the range of new behaviors for consideration because it generates different and more varied outcomes and co-occurrences than working alone (Simonton, 2003a).

Other factors proposed to foster innovating include contexts that change, ample free time and energy, and low social rank (Kummer & Goodall, 1985; Reader & Laland, 2001). Development (age/sex) can both foster and constrain innovating via the changes it generates in individuals' interests, behavioral repertoires, cognitive abilities, social roles, ranging, novelty orientation, conformity, and independence (Box, 2003; Greenberg, 2003; R. B. Payne, 1996; Reader & Laland, 2001; Russon, 2003a; Simonton, 2003a). Its effects are likely to be pronounced in taxa with slow life histories

like primates, cetaceans, and some birds because developmental changes are marked (Box, 2003; Mann & Sargeant, 2003; Reader & Laland, 2001; Simonton, 2007; Slater & Lachlan, 2003). In nonhuman primates, juveniles are often deemed the most innovative (Box, 2003; Kummer & Goodall, 1985) but meta-analyses identified adults (Reader & Laland, 2001).

### Studying Innovation in the Field

Field studies of innovation are important complements to experimental and captive studies. Novelty related behavior can differ between captive and natural contexts (Greenberg, 2003; Lefebvre & Bolhuis, 2003) and should do so, given that environmental pressures, social conditions, development, and learning affect the qualities and rates of innovation. What natural contexts offer is views of species normal innovation, being closer to the contexts for which innovation was selected and designed to operate (Kummer & Goodall, 1985; Lefebvre & Bolhuis, 2003; Logan & Pepper, 2007; Ramsey et al., 2007; van Schaik et al., 2006). Despite methodological advances in the study of innovation in the field, important challenges remain (see Ramsey et al., 2007 and commentaries). Field studies are unlikely to detect creative events, for instance, so innovations are identified retrospectively (Greenberg, 2003). We addressed three methodological issues now facing field studies of orangutan innovation: the data used to identify innovations, how to identify innovations empirically, and how to study innovative processes.

Pioneering field studies, including those on orangutans, identified innovations from preexisting data collected for other purposes and knowledgeable professionals' impressions that some behaviors were unusual, unique, or rare (Byrne, 2003; Lefebvre et al., 1997; Reader & Laland, 2001; Reader & MacDonald, 2003; van Schaik et al., 2006). Although this work has been groundbreaking, these data are clearly problematic.

To identify innovations empirically, field studies typically single out behaviors that differ from species- or population- typical ones in quality and/or prevalence, such as unusual motor patterns, food types, or usage (e.g., Byrne, 2003; Greenberg, 2003; Lefebvre et al., 1997; Reader & Laland, 2001; van Schaik et al., 2006; Weinrich, Schilling, & Belt, 1992). A prerequisite to making these judgments is separating behavioral differences that are functional (variants) from those that are minor and facultative (modifications; Hauser, 2003; Ramsey et al., 2007; van Schaik et al., 2006). Moss wipers and leaf wipers would not qualify as different variants if tool object choice is facultative, for instance, so even if moss wipers are unusual they would not qualify as innovative. Valid separation requires parsing behavior at the correct grain, the level of detail at which actors distinguish, acquire, and organize behavior (Byrne, 1999; Rendell, Hoppitt, & Kendal, 2007; Russon et al., 2009). For taxa that can organize behavior at multiple levels, like humans, great apes, and some songbirds and cetaceans (Byrne & Byrne, 1993; Marler, 1991; K. Payne & Payne, 1985; Slater & Lachlan, 2003; Ward, 2007), observers must parse behavior at the same levels that actors do. This is not straightforward because parsing rules can be species specific (Marler, 1991). Great apes and some corvids show considerable facultative flexibility in their choice of objects to use as tools, for instance, but other species may not (Russon et al., 2009; Weir, Chappell, & Kacelnik, 2002; Weir & Kacelnik, 2006). Some wild orangutan innovations may

have been misidentified because grain was not considered in separating variants from modifications (Russon et al., 2009).

A useful approach to studying innovative processes in natural contexts is reconstructing the behavioral pathway that led to a given innovation (Byrne, 2003; Rendell & Whitehead, 2001; Slater & Ince, 1979). This involves inferring an innovation's precursor(s), that is, the behavior(s) from which it derived. Studies that track change as it occurs are clearly preferable (e.g., K. Payne & Payne, 1985; R. B. Payne, 1996), but reconstructions have proven valuable in suggesting how change occurred, even if when and where are uncertain (Slater & Lachlan, 2003).

### The Current Study

We undertook a field study of orangutan innovative processes, involving 20 months' systematic observation of rehabilitants' water-related behavior on Kaja, a seasonally inundated island in Central Kalimantan, Indonesia. We chose water for a several reasons. Water is a normal feature of orangutan habitat, tropical rainforests near rivers, but orangutans rarely engage with it, especially on the ground because ground water presents risks from predators (snakes, crocodiles) or drowning (orangutans cannot swim) and it offers no normal foods. Innate predispositions are then improbable so water competencies are almost certainly learned, making water fertile ground for innovation. On Kaja, water posed a variable set of interrelated tasks (e.g., travel and food retrieval altered by seasonally changing water levels), which should facilitate assessing how water variants are related. Our aims were to infer innovative processes by identifying the water-related innovations in this population then reconstructing the behavioral pathways to them. We documented all water-related behaviors as a basis for establishing the population's repertoire, quantifying variant prevalence, identifying innovations, and tracing relations between variants. Other studies have used similar approaches (e.g., Slater & Ince, 1979). We used findings on the organization and grain of great ape behavior to distinguish variants (Byrne, Corp., & Byrne, 2001). We tested for innovating by small changes to precursors and assessed influences of all four contributing events, age, sex, and social rank.

### Method

#### Subjects

Subjects were 43 ex-captive Bornean orangutans (*Pongo pygmaeus*) living semifree on Kaja Island, from April 2004 to December 2005. All were placed on Kaja between November 2001 and January 2004, by the Borneo Orangutan Society (BOS) Foundation's Orangutan Reintroduction Project at Nyaru Menteng (NM), as their final stage of rehabilitation before returning to forest life. Most were juveniles or adolescents; during the study no new orangutans were moved to Kaja but three females became primiparous. Ages are estimates midway through the study (December 2004), based on dental eruption at intake per NM medical records. Backgrounds varied in age on arrival, duration of captivity and life at NM, and living conditions before moving to Kaja. In most cases, captive living conditions before arriving at NM cannot be determined.

#### Setting

Observations were made at Kaja Island, a 108.5 ha island in the Rungan River, Central Kalimantan, Indonesia (S 2°1', E 113°47'). Its habitat is native forest mixed with a few old gardens that produces a good range of orangutan foods; much of it is seasonally inundated (Sidiyasa, 2001; Sidiyasa, Arifin, & Abadi, 2001). During our study, NM delivered supplemental provisions to several feeding platforms around the island twice daily and monitored rehabilitants' behavior for 2 to 4 hr daily. Provisions were local produce (e.g., sugarcane, coconuts, greens, corn). NM schedules focused our observations on canoe-accessible areas near feeding platforms, between morning and afternoon provisioning (2004: between 8:00–17:00, 2005: between 9:00–15:30).

#### Data Collection

All four authors collected observational data on orangutans' water-related behavior, by continuous event recording within focal individual samples. For maximum coverage, we recorded all events of water behavior observed during focal samples, in any orangutan. We corroborated questionable activities with each other and NM staff. We coded water events for behavioral content (detailed descriptive narratives), actor, location, social interaction (e.g., steal, scavenge, beg, observe, share, copy), and other influences (e.g., disruptions, weather). We also recorded the flow of standard behaviors (feed, travel, rest, play) in similar fashion. We recorded social associations by instantaneous scans at 5-min intervals, recording the identities of all orangutans in association (5–50 m) and in close association (<5 m) with the focal orangutan.

#### Measures

**Water variants.** Per van Schaik et al. (2006) and Ramsey et al. (2007), variants were behaviors that differed in form and outcomes, and modifications were minor differences in behavioral form without evident functional significance (e.g., details of actions, items used). Meticulous analyses by Byrne et al. (2001) showed three levels of organization in great ape behavior: elements (behavior details; e.g., tool objects, motor actions), procedures (combinations of elements that achieve a specific goal; e.g., clean with a wiper), and programs (procedure-element combinations that achieve broader goals; e.g., stone nut crack). Programs are probably stable once acquired, while lower level components remain modifiable, to allow adjustment to local contingencies. Elements are typically acquired by trial and error and highly flexible, while procedures tend to be more stable. We therefore distinguished variants at the procedure level (e.g., wiper vs. leaf wiper and moss wiper) unless evidence indicated that details were functionally distinctive to actors.

**Water innovations.** We identified innovations as water variants that were rare on Kaja (Greenberg, 2003; Lefebvre et al., 1997; van Schaik et al., 2006), considering them rare if we observed them in <20% of Kaja residents. These criteria are conservative in that they ignore locally common innovations. There is no implication that the performances we observed were the generative ones or that all orangutans that performed an innovation created it independently. For convenience, we refer to orangutans observed to perform an innovation as innovators.

**Reconstructing pathways to innovations.** If innovating operates by changing existing behavior, it should be possible to reconstruct the behavioral pathway that generated each innovation, that is, the precursor(s) from which it derived. We allowed for multiple precursors, in succession, leading to the innovation (Byrne, 2003; Russon, 2003b; Russon et al., 2009).

Precursors were identified by similarity of function and form. Similar function implies similar task, so we first identified all water tasks that Kaja orangutans faced. This was a post hoc exercise based on our complete database of Kaja orangutans' water behavior. Task differences could be a matter of degree (e.g., travel in water vs. through it, travel vs. play in water), so we defined some tasks at multiple levels. We considered variants functionally similar if they addressed the same or similar tasks. Some tasks also served multiple functions (e.g., travel and social) so we assessed variants relative to all evident functions in an effort to tease out which most affected actors. Potential precursors for each innovation were then identified as other variants used for similar functions and similar in behavioral form.

We reconstructed the behavioral pathway to each innovation by ordering its precursors from most to least common (i.e., total orangutans users). Innovations, by definition rare, appeared at the ends of these sequences. An innovation's direct or immediate precursor was the precursor closest to it in function, form, and prevalence. We later searched for precursors in nonwater contexts, based on similar form and similarities in function irrespective of water.

**Social rank.** We assessed social rank from win-loss patterns in dyadic encounters with asymmetrical outcomes (interrater reliabilities for asymmetrical outcome assessments were 0.90). In consideration of dyads that were not recorded interacting and rank changes over the course of the study as orangutans matured, we grouped orangutans into three equal rank classes, high, medium, and low.

**Associations.** We identified each orangutan's associates during water behaviors from scan data. We defined associates and close associates, respectively, as orangutans  $\leq 50$  m and  $\leq 5$  m from the focal (50 m is the standard for wild orangutan association, 5 m has proven useful in identifying rehabilitant affiliative networks; see Russon, Handayani, Kuncoro, & Ferisa, 2007).

## Results

We collected 1,397 hr of observational data on Kaja rehabilitants' behavior over 20 months, yielding 1,452 water events in 41/43 rehabilitants. Hours of observation varied between orangutans (5–79 hr,  $M = 32.5$ ,  $SD = 16.8$ ), mainly due to differential accessibility. Adolescent males' increasing aggressiveness in particular increasingly restricted observations to safe, boat-accessible areas for 1 to 2 hr around feeding times. For the 41 orangutans we observed in water activity, hours of observation did not correlate significantly with being an innovator ( $r = .22$ ,  $p = .16$ ) or number of innovations ( $r = .20$ ,  $p = .21$ ) but did with number of water events ( $r = .32$ ,  $p = .04$ ) and water variants ( $r = .31$ ,  $p = .05$ ). We therefore restricted analyses to orangutans with five or more water events ( $n = 39$ , 1,444 events) and whether rather than how often each orangutan used each water variant. With this limitation, correlations with hours of observation were all nonsignificant (innovator:  $r = .35$ ,  $p = .15$ ; number of innovations:  $r = .32$ ,  $p =$

$.16$ ; events:  $r = .28$ ,  $p = .09$ ; variants:  $r = .22$ ,  $p = .17$ ). This yielded 44 water variants, where variants were included if they were performed at least twice; 18/44 variants qualified as innovations (see Table 1). All statistical analyses were performed with SAS 9.1.3. For multiple-statistical tests, significance levels reported are false discovery rate (FDR) adjusted.

## Change Preexisting Behavior

We tested two implications of the model of innovating by changing existing behaviors: the broader the range of an orangutan's water behaviors, the more water innovations they should produce; and an innovation should occur only in orangutans that also used its precursors, especially its immediate precursor. As predicted, total water events and total water variants, respectively, correlated strongly with being an innovator (one-sided tests,  $r = .60$ ,  $p < .001$ ;  $r = .69$ ,  $p < .001$ ) and with total innovations ( $r = .79$ ,  $p < .001$ ;  $r = .80$ ,  $p < .001$ ).

**Precursors within tasks.** To identify precursors for each innovation, we first grouped all water variants by the water task they addressed. Water behavior data indicated five broad water tasks (retrieve item, drink, travel, social water use, play/bathe); most included narrower subtasks requiring specialized techniques (e.g., retrieve floating vs. sunk item). For an innovation, we took the other variants used for the same task/subtask as probable precursors and ordered them by prevalence to reconstruct the behavioral pathway. We excluded play as not task defined and social techniques for ecological tasks as alternative versus related variants. Figure 1 (a through d) shows the pathway to each innovation for retrieving items, considered as multiple subtasks. Appendix A shows these pathways when retrieving items are considered one broad task.

For each pathway, we assessed dependencies between each innovation and its immediate precursor and between adjacent precursors. For intercept, for example, the pathway for the subtask identifies the immediate precursor as chase (Figure 1c), whereas the pathway for the broad task identifies pull (see Appendix A). We used McNemar's change test (Siegel, 1956) to assess directional dependencies: that is, an innovation was unlikely without its immediate precursor compared to the reverse.

Within broad tasks, evidence for directional dependencies was generally unconvincing. In retrieving items, for example, pull and soak did not depend on their ostensible immediate precursor, rengas; deep depended on basic but probably because basic was almost universal (see Appendix A).

Within narrow subtasks, significant dependencies were found for most innovations on their immediate precursor (all but fish, sex, distract, hide, splash, sand) and between adjacent precursors, for up to three precursors per innovation (Table 2; Figures 1b to d, Appendix B). Effect sizes showed that actors were much more likely to perform the immediate precursor but not the innovation than to perform the innovation but not the immediate precursor (odds ratios 8–65, Table 2). Lack of statistical dependency between fish and soak is probably a numerical artifact (the one orangutan that used fish also used soak); sand and social patterns are better explained by dependencies we treated as between tasks dependencies and transfer (see Figure 2 and below). Pathways also show that innovators for one narrow task often used only common variants in related narrow tasks (see Figure 1). Overall, for eco-

Table 1  
*Kaja Orangutans' Water Variants and Innovations*

Name	Variant description	Total events	Total OUs
Retrieve items from water			
Floating items			
Basic	Simple pick up item from shallow water (floating still or visible sunk) or within reach from river bank	289	38
Deep	Retrieve item floating still in deep water; travel within reach of item (climb to position above, wade close); pick up item	50	25
Chase	Chase item floating away with a current; locomotion variable (arboreal, water, land); grab when within reach	24	19
Rake	Find/make rake tool, extend toward floating item out of reach; once hooked, rake item within reach, pick up item	20	11
<u>Soak</u>	Dip sugar cane into water, allow to absorb water, suck out absorbed water (and whatever it dissolved)	4	3
<u>Pull</u>	Dip hand into water between self and floating item out of reach, repeatedly pull water toward self (create small current to draw item closer); pick up item once in reach	6	3
<u>Intercept</u>	Intercept item floating away with a current by anticipating its trajectory (meet it, or ambush it from the front); locomotion variable (arboreal, land, water); grab if intercepted	2	2
<u>Fish</u>	Eat dead fish (found floating)	1	1
Social	Observe, copy, beg, steal, scavenge	29	14
Sunk items			
Grope	In deep water, reach to pond/river bottom, grope around, pick up any items discovered	41	15
<u>Rengas</u>	Eat old rengas fruit, waterlogged, retrieved from pond bottom (rengas fruit is a hard-shelled forest fruit that grows on Kaja)	12	7
<u>Probe</u>	Use stick to probe for items sunk in water	1	1
Social	Observe, copy, beg, steal, scavenge	17	9
Drink			
Direct	Sip directly from surface of water or dip hand in water then lick/dribble/splash water into mouth	64	24
Cup	Scoop water into cup-like container (e.g., cup, shell), drink	14	9
<u>Sand</u>	Use existing hole on beach filled with water, or dig hole on beach and wait until it fills with water, drink from hole	5	5
<u>Sponge</u>	Absorb water with sponge-like item (commercial sponge, corn or coconut husk, plastic bag, cloth), drink from sponge	2	2
<u>Br-dip</u>	Dip leafy twig into water, drip water from twig into mouth	1	1
Social	Observe, copy, beg, steal, scavenge	4	3
Water-related travel			
Wade-s	Wade through shallow water	101	30
Wade-d	Wade through deep water	133	34
Wade-ds	Wade through deep water with above-water support (e.g., liana)	76	31
<u>Ruler</u>	Insert long stick into water to test water depth	2	2
Bridge	Bend slender tree until its leafy branches lie on water then clamber along tree across water (new 21/14); or use old bridge (old 25/16)	43	27
Arboreal	Travel arboreally across a body of water	28	18
<u>Boat</u>	Travel on floating log to cross a body of water	3	3
<u>Br-hook<sup>a</sup></u>	Make/use stick to catch hold of and draw in leafy tree branches, to enable arboreal travel over water; one stick had a hook end	2	1
Swim-s	Travel in water by floating, with support, that is, hold vegetation for support, pull on vegetation to propel body	31	16
<u>Swim</u>	Travel in water by floating, without support, that is, gliding free or making rudimentary paddling motions	3	2
Social	Socially guided travel (follow route/travel technique)	10	10
Social use of water			
<u>Splash</u>	Splash water to attract attention (display-3, invite play-1)	4	4
<u>Hide</u>	Hide by entering water, typically submerging so only the top of the head is above water; also once behind large branch	5	4
<u>Distract</u>	Engage in affiliative/neutral activity with water, typically near the water's edge, in apparent deception (real intent: cross river)	4	4
<u>Sex</u>	Male pulls female into water vegetation and copulates there (perhaps as a place difficult to disturb)	1	1

(table continues)

Table 1 (continued)

Name	Variant description	Total events	Total OUs
Water play/bathe			
Bathe	Splash and rub water over body parts	41	18
Idle	Sit/lie, inactive, in shallow water	46	16
P-soli	Sit/roll in water, splash/pour water, spurt/rinse mouth, and so forth	110	26
P-sand	Sand play involving water near river's edge	43	18
P-object	Object play involving water (e.g., moss/sack/leaf sponge, fishing net, branch, bottle, crate, dead fish)	23	11
P-swim	Swim-like actions in water without clear functional goals, that is, glide around in water, with support	18	8
P-tool	Tool play: cup (14/8), probe (2/2), sponge (7/7), wet item (9/7), wash item (17/10), wiper (8/6), splasher (5/5), digger/scrapper (6/5), probe (1/1), boat (1/1)	51	40
<u>Submerge</u>	Deliberately submerge entire body underwater, head included	2	1
P-social	Play in water with companions	60	15

*Note.* Variants identified as provisional innovations are underlined. OU = orangutan; shallow/deep water = under/over waist deep; Splash = attention getting versus affective because great apes appear to act voluntarily to gain attention but communicate affect otherwise (e.g., facial expressions, piloerection; Call & Tomasello, 2007).

<sup>a</sup> We observed partial br-hook manufacture once. On observers' arrival, Jane (juvenile female) was using a br-hook to catch an outer branch of a large tree that arched over the river. Her br-hook was a slender tree, recently downed (leaves were still green), with a distinct "hook" at the base (approx. 10 cm long) that would have resulted from its having been broken at root level. The nature of the break, the fresh leaves, and multiple observations of orangutans crossing this river at this spot via this tree during this period all suggest the tree did not fall naturally, an orangutan broke it. The manufacture we observed was Jane's shortening the br-hook by removing leafy branches from its tip, possibly to facilitate maneuvering it. Jane appeared to make deliberate use of the hook: She always held tree by its tip, repeatedly extended the basal hook into the target branch, manipulated the tool so that its hook caught the branch's leafy twigs, and then drew it in. She failed to get the branch because, while drawing it in, the leafy twigs always slipped from the hook.

logical tasks, findings support innovating by making small changes to preexisting behaviors used for the same or narrowly similar tasks.

**Precursors from other tasks.** Four innovations may have derived from variants we had attributed to other tasks: sand from p-sand (both often included digging sand holes), submerge from grope (for deep water foraging, to better retrieve sunk foods and escape theft), and soak from rengas (eating sunken rengas, a hard-shelled forest fruit, and sugarcane when dry—both familiar Kaja foods). Our data allowed testing of innovator-precursor dependencies for sand and submerge; McNemar tests confirmed both (see Table 2).

### Transfer: Use Preexisting Behavior for New Purposes

If transfer contributed to water innovations, then innovators should also use the same or similar variants for other tasks. We tested this for tool use because it was salient to observers and applicable across contexts, and we had systematic tool use data for Kaja. We identified tools as freely manipulatable objects that an actor controlled with the aim of physically altering a target by dynamic mechanical action (Amant & Horton, 2007); by these criteria, we identified 15 tools that Kaja orangutans used in water tasks (nine qualified as innovations, hereafter tool innovations) and 38 used in other contexts (play, nonwater tasks). Like K. Payne and Payne (1985), we accepted some atypical variants (notably, wet, wash, and soak items) because our interests concerned what similarities among tool-like variants show about innovating, not whether variants qualified strictly as tools. We treated these three variants as tool use because water was manipulated and it served as the tool (see also Mendes, Hanus, & Call, 2007).

For each tool innovation, we identified similar tools as tools with similar form and function but used for different tasks and contexts (play, nonwater). In case degree of similarity affected transfer potential, we assessed innovators' tool use at three levels: closely similar, broadly similar, and generalized (total number of different tools used on Kaja). Rake, ruler, probe, br-hook and scratcher are broadly similar (sticks used to access distant targets), for example, but some also share closer similarities (e.g., retrieve target, detect target). We tested for transfer by correlating use of tool innovations with use of similar tools (see Table 3). For each tool innovation, positive correlations were predicted with similar but not dissimilar tools; no individual predictions were made for correlations with generality of tool use.

For five tool innovations, correlations with using closely similar tools were significant; they neared significance for a sixth. This confirmation rate is significantly better than chance (5/10 predicted vs. 6/62 other correlations significant: Fisher's exact test, one-tailed,  $p = .02$ ). For correlations with using broadly similar tools, none reached significance but three neared significance. Correlations with generalized tool were significant for three tool innovations and neared significance for a fourth. Effect sizes for significant correlations were moderate to large (15–46% of the variance; Cohen, 1988), suggesting that transfer contributed to tool innovations but was not the only influence involved.

Further, five nontool water innovations (intercept, distract, hide, sex, splash) may have owed to technique transfer from nonwater contexts because orangutans are known to intercept competitors or prey in pursuits, distract with neutral or affiliative activities, hide behind visual barriers, copulate in seclusion to avoid interference, and display to gain attention (Byrne, 2003; Russon et al., 2009; van

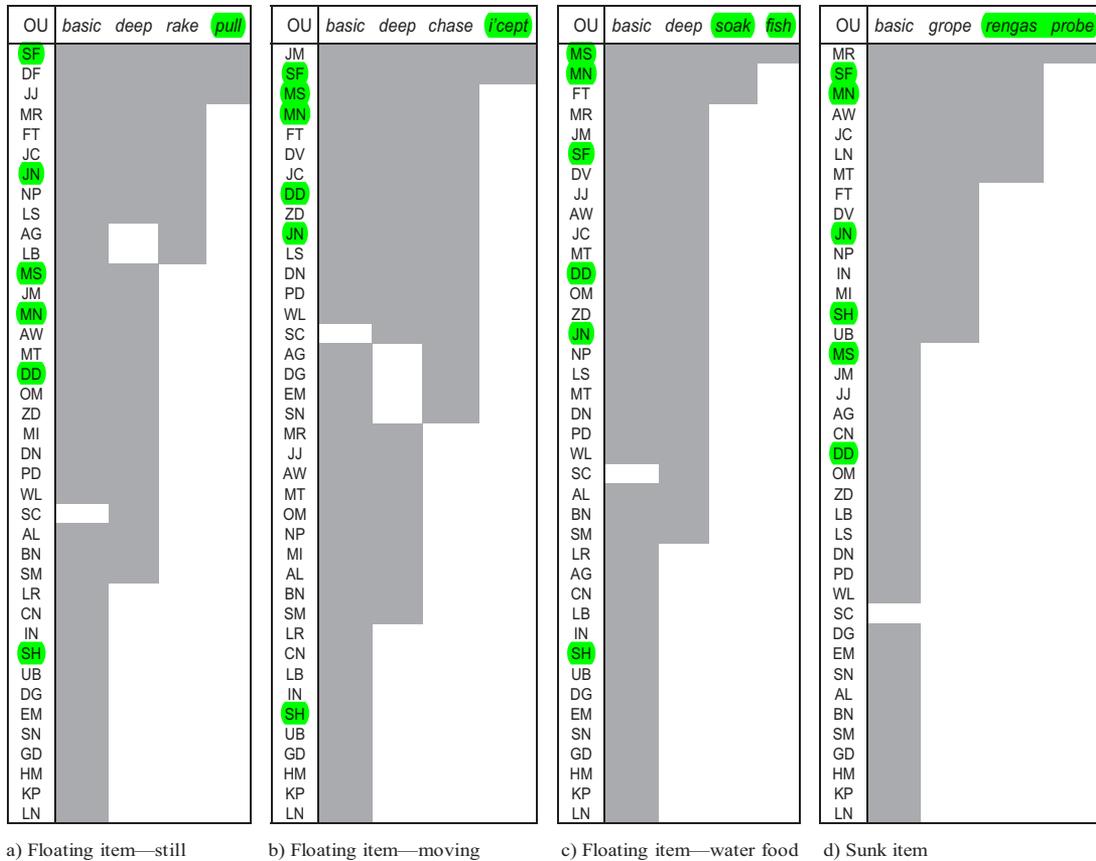


Figure 1. Behavioral pathways for retrieving items from water, as narrowly defined tasks (a through d). Column headers: orangutan (two-letter name code), variant label (number of variant users). Cells: shaded = user; unshaded = nonuser. OU = orangutan.

Schaik et al., 2006). These five innovations differ only in the behavioral detail used in water contexts: intercept in trajectory constraints, and the four social innovations in using water as a medium for display, neutral activity, or barriers (physical or visual).

Finally, swim may transfer arboreal locomotor skills. As a travel substrate, the forest canopy is characterized by compliance and discontinuities (i.e., gaps; Povinelli & Cant, 1995). So is water, in its buoyancy and drop-offs in depth. To cross canopy gaps, orangutans often use or manipulate compliance by lunging while holding foliage at one side of a gap, then grabbing foliage on the other side; rarely, for very narrow gaps, they may jump across. This is much like swimming we observed: lunge while holding foliage at one edge of a water gap and grab foliage on the other side (swim-s) or rarely, lunge, free-floating, across narrow (approximately 1 m) gaps (swim).

### Accidents

We found no way to test for fortuitous discoveries systematically, but accidents we observed could have sparked 11 innovations. Possibilities are: sponge, rengas, fish, soak (water-altered items retrieved fortuitously while searching water for familiar foods), sand (encounter sand hole already water filled; side effect

of sand hole digging in play), submerge (accidental swamping by passing boats), splash (side effect of display near water; e.g., throw object), hide (fortuitous invisibility when neck deep in water), swim (accidental fall into deep water), boat (climb on log to cross water, not realizing it is floating), and pull (side effect of failed attempt to retrieve floating items out of reach). To explain *pull*, attempts to retrieve floating items out of reach often included lunging while holding vegetation with one arm and reaching with the other. On failing, the reaching arm plunged into water in front of the item and recoil from the lunge dragged it back to the orangutan. This created a current, drawing the item closer.

### Independent Working Out

We tested independent working out for ecological innovations, on the prediction that these may owe much to working away from social distraction (Kummer & Goodall, 1985). We compared close association rates at performances of very rare ecological innovations (1–2 users,  $n = 10$ ) versus more common ones. We chose these performances as potentially closest to innovating and close associations as more distracting than distant ones. We compared innovator with noninnovator associates, expecting the former to be the more distracting. Close association rates were the number of close associates and interactants per performance. For innovator

Table 2  
*Innovating by Changing Precursors: McNemar Tests for Dependencies in Behavioral Pathways*

	Behavior pathways precursors ( $p_i$ ) to innovations ( $i$ ) <sup>a</sup>						Directional dependencies effect sizes, significance levels <sup>b</sup>			
	$p_3$	→	$p_2$	→	$p_1$	→	$i$	$p_3 \rightarrow p_2$	$p_2 \rightarrow p_1$	$p_1 \rightarrow i$
Retrieve floating item										
Moving	Basic		Deep		Chase		<u>Intercept</u>	29.0 <sup>***</sup>	2.5	<u>35.0<sup>***</sup></u>
Out of reach	Basic		Deep		Rake		<u>Pull</u>	<u>29.0<sup>***</sup></u>	8.0 <sup>**</sup>	<u>17.0<sup>***</sup></u>
Water foods	Basic		Deep		<u>Soak</u>		<u>Fish</u>	<u>29.0<sup>***</sup></u>	<u>45.0<sup>***</sup></u>	<u>5.0</u>
Retrieve sunk item	Basic		Grope		<u>Rengas</u>		<u>Probe</u>	<u>47.0<sup>***</sup></u>	<u>17.0<sup>**</sup></u>	<u>13.0<sup>*</sup></u>
Drink										
From sand hole			Direct		Cup		<u>Sand</u>		8.5 <sup>**</sup>	2.3
Using sponge			Direct		Cup		<u>Sponge</u>		8.5 <sup>**</sup>	8.0 <sup>*</sup>
Branch dip			Direct		Cup		<u>Br-dip</u>		8.5 <sup>**</sup>	<u>17.0<sup>*</sup></u>
Water travel					Wade-d		<u>Ruler</u>			<u>65.0<sup>***</sup></u>
On water			Wade-d		Bridge(old)		<u>Boat</u>		6.3 <sup>**</sup>	<u>23.0<sup>***</sup></u>
In water			Wade-d		Swim-s		<u>Swim</u>		<u>37.0<sup>***</sup></u>	<u>29.0<sup>***</sup></u>
Over water			Wade-d		Arboreal		<u>Br-hook</u>		18.0 <sup>***</sup>	<u>33.0<sup>***</sup></u>
Social use of water					<u>Splash</u>		<u>Sex</u>			4.0
					<u>Hide</u>		<u>Sex</u>			4.0
					<u>Distract</u>		<u>Sex</u>			4.0
Between tasks			Direct		P-sand		<u>Sand</u>		4.0	<u>27.0<sup>***</sup></u>
					Grope		<u>Submerge</u>			<u>29.0<sup>***</sup></u>

<sup>a</sup> Behavioral pathways show the precursor sequence predicted to generate each innovation. <sup>b</sup> McNemar tests assessed whether performing a variant in a behavioral pathway depended on performing its immediate precursor. Significance levels are false discovery rate-adjusted, treating all McNemar tests as one family (\*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ). The odds ratio (OR) for off-diagonal cells measures McNemar test effect size (Faul, Erdfelder, Lang, & Buchner, 2007). Values reported use the probability of performing a variant but not its immediate precursor as the denominator. For tables with a zero cell, we used a standard .5 continuity correction to calculate the odds ratio; corrected OR values are underlined.

but not noninnovator associates, close association rates were significantly lower at performances of the rare innovations (one-sided median tests, respectively:  $S = 1.64$ ,  $p = .001$ , *ns.*). In fact, performances of these rare innovations had no innovator close associates. This is consistent with independent working out.

We examined whether practice may have contributed to innovating by assessing whether orangutans performed innovative water skills in water play (tool use, submerge, pull). Practice often hones skills and play is conducive to practice (Burghardt, 2005). Submerge and seven of the nine tool innovations were performed in water play (see Table 3). In play, submerge suggested both limited skill and practice. Qualitative evidence is also consistent with independent working out for one tool innovation, ruler. Ruler may have been generated to handle developmental change: both users were primiparous mothers and both used ruler to test deep water while carrying young infants. One used no other tools or similar behaviors that could have served as ruler precursors, suggesting she worked out this solution independently.

**Social Cross-Fertilization**

Close associations may best offer the best opportunities for social input (Coussi-Korbel & Fragaszy, 1995) and interesting models, highly proficient models, or unusual behavior may best attract attention and inspire innovation (Kuczaj & Yeater, 2006; Ottoni, de Resende, & Izar, 2005). Innovators may then selectively associate closely with other innovators or performances of water innovations and/or their immediate precursors.

Innovators' rates of close association with other innovators were disproportionately high and between noninnovators they were disproportionately low,  $\chi^2(3) = 273.26$ ,  $p < .001$ ; the effect size is

large (Cohen's  $w = 0.54$ ). Social techniques (copy, co-act, observe, give, beg, steal, displace, scrounge) also targeted innovators much more than noninnovators (being an innovator  $r = .58$ ,  $p = .001$ ; total innovations  $r = .73$ ,  $p < .001$ ).

Innovators' rates of close association with water innovations and immediate precursors were significantly higher than noninnovators' were, but the same pattern also held for common water variants (see Table 4). Some interactions, however, suggested selective attention to unusual behaviors. Social techniques targeted eight water variants more than expected (grope, rengas, bridge (old), boat, wade-d, arboreal, direct, sand; chi-square or Fisher's exact tests, all  $p < .05$ ); half (4/8) are innovations or immediate precursors and most (6/8) tackle opaque tasks, that is, tasks with invisible features (e.g., water depth, sunk items, floating substrate). During performances of water innovations ( $n = 20$ , 11 innovations), orangutans that used the same innovation (co-innovators) tended to co-act or observe but those that did not use this innovation tended to compete (Fisher's exact test,  $p = .08$ ). Half of the water innovations that co-innovators observed or co-acted with address opaque tasks. This suggests that unusual variants did elicit selective attention, if variants for handling opaque tasks are included.

To assess social cross-fertilization, we examined orangutans' behavior after observing or co-acting with innovations or immediate precursors for opaque tasks (grope, rengas, bridge [old], boat). For behavior addressing opaque tasks, social input can influence but not determine behavior (Zentall, 2006). If cross-fertilization occurred, then partners' behaviors should resemble but not duplicate the model. Three cases showed relevant qualities; we describe one. Markisa watched Leonora grope in deep water, saw

OU	hide	distract	splash	sex
JC				
LB				
AG				
FT				
JN				
JJ				
MS				
NP				
MR				
IN				
MI				
LR				
DD				
EM				
LS				
MT				
MN				
AL				
AW				
BN				
CN				
DG				
DN				
DV				
GD				
HM				
JM				
KP				
LN				
OM				
PD				
SC				
SN				
SH				
SF				
SM				
UB				
WL				
ZD				

Figure 2. Behavioral pathways for social water use. Column headers: orangutan (two-letter name code), variant label (number of variant users). Cells: shaded = user; unshaded = nonuser. OU = orangutan.

her retrieve sugarcane, and tried to steal it. Leonora fled, dropping the cane in deep water. Markisa searched the water where the cane fell, but only shallow areas. She did not find it; then searched for a stick and probed it in deeper areas (plunged it in, scraped it along the bottom, pulled it out, poked it around). Important here is that observing grope led to probe. Markisa was highly proficient at groping for foods in deep water, so she may have probed rather than groped because she was carrying a young infant.

### Age, Sex, and Social Rank

Neither age nor sex correlated with being an innovator (respectively,  $r = .19, p = .25$  and  $r = -.08, p = .62$ ) or total innovations (respectively,  $r = .10, p = .56$  and  $r = .02, p = .92$ ). Social rank (high, mid, low) was significantly related to being an innovator (Fisher's exact test  $p < .02$ ) and neared significance for number of water variants (Fisher's exact test  $p < .10$ , Table 5). Midrank orangutans were most often innovators and used the most water variants; notably, low-rank orangutans were least often innovators.

### Discussion

This study has limitations and biases to weigh in assessing findings. Methodologically, it shares limitations intrinsic to obser-

vational field studies of innovation and ahistorical approaches to the study of historical phenomena. We extended methods, however, to improve identification of innovations and innovative processes in orangutans. Our main methodological concern is that we may not have parsed behaviors well enough to identify the similarities most meaningful to actors. The models of great ape cognition we used are not the only ones available, however, and others may generate different or better solutions. Encouraging is that the patterns these models revealed are consistent with other findings on great ape behavior in natural contexts.

The innovations themselves need examination because they found inferences about innovative processes. Most striking is the range of probable water innovations in this one, small rehabilitant population: It dwarfs that identified for all wild orangutan populations combined (van Schaik et al., 2006) and includes highly inventive behaviors like fish eating and swimming, neither reported in orangutans elsewhere (e.g., Stewart, Gordon, Wich, Schloor, & Meijaard, 2008). Several factors could have enhanced the innovation rate: Kaja's very watery habitat, rehabilitants' experiences as orphan ex-captives, and humans. Habitat effects were probably limited. Wild orangutans ranging in equally watery habitat (Sungai Lading, Central Kalimantan) showed at most four water innovations: three ways to drink, and wade to bathe (M. Bastian, personal communication, 7/30/2007). Orphaning may have enhanced innovativeness by encouraging independence and nonconformity (Russon et al., 2009; Simonton, 2003a, 2003b), as might Kaja's atypical social life, by enhancing opportunities for social input. Humans probably fostered water innovations: Their support increased rehabilitants' freedom from environmental pressures, they induced much of the water use on Kaja, they induced atypical innovations in the wild in other species, and they may increase innovation rates in captive primates (Hinde & Fisher, 1972; Kummer & Goodall, 1985; Lefebvre et al., 1997; Mann & Sargeant, 2003; Reader & Laland, 2001). Available evidence suggests rehabilitants' innovation rates are higher than those in the wild, but their innovations are similar in kind and their innovative processes show no signs of alteration (Russon et al., 2009). Kaja innovations then offer a credible basis for inferring the processes that generated them.

### Innovative Processes

Our findings offer some support for all the innovative processes assessed (see Table 6). Innovating by making small changes to precursors was evident for all water innovations, except possibly ruler. This was clearest within narrowly defined ecological tasks, and less evident for broadly defined tasks, social tasks, and play. Applying old behavior to new purposes (transfer) may have contributed to 12 innovations. Tool use correlations suggest transfer from closely more than broadly similar skills, but perhaps at general levels for a few individuals. Accidents may have inspired 11 innovations. Independent working out was probable for 13 innovations and possible for 17, mostly ecological skills; mental working out was suggested in two cases. Social cross-fertilization was possible for seven innovations. Innovators had good opportunities for social input, especially from other innovators, and appeared to use them; social input may have influenced but underdetermined innovations for handling opaque tasks.

Table 3  
*Innovation by Transfer: Pearson Correlations Between Actors' Use of Innovative Water Tools (Rows) and Their Use Similar Tools (Columns)*

Water tool <sup>a</sup>	Also in play	Closely similar tools <sup>b</sup>								Broadly similar tools <sup>b</sup>			Breadth of tool use
		Reacher	Probe	Wet	Cup	Sponge	Attention	Boat	Hide	Stick	Cup	Wet/sponge	
Ruler	1/2	<u>.00</u>	-.10	-.16	.13	-.13	-.20	.26	.22	<u>-.07</u>	.10	-.18	-.05
Br-hook	0/1	<u>.47**</u>	-.07	-.11	.48**	-.09	.35 <sup>†</sup>	-.06	-.07	<u>.26</u>	.57***	-.12	.50**
Probe	1/1	.28	<u>.52**</u>	.07	.09	-.09	-.14	-.06	.38*	<u>.26</u>	.07	.01	.23
Br-dip	1/1	-.10	-.07	<u>.40*</u>	.09	.20	.11	-.06	-.07	-.09	.07	<u>.33<sup>†</sup></u>	.08
Soak	1/3	.27	.17	.02	<u>.39*</u>	<u>.06</u>	.19	.18	.14	.32 <sup>†</sup>	<u>.32<sup>†</sup></u>	<u>-.03</u>	.41**
Sponge	1/2	.27	.26	-.03	<u>.27</u>	<u>.40*</u>	.32	-.09	-.10	.31 <sup>†</sup>	.22	<u>.12</u>	.30 <sup>†</sup>
Splash	3/4	<u>.59**</u>	<u>.38*</u>	.23	<u>.50**</u>	.27	<u>.37<sup>†</sup></u>	-.13	-.14	<u>.59***</u>	<u>.58***</u>	.29	<u>.68***</u>
Boat	0/3	.04	-.13	-.09	-.06	.01	-.24	<u>-.07</u>	-.08	-.11	-.07	-.04	-.06
Hide	1/1	.28	<u>.69**</u>	.07	.09	-.09	-.14	-.06	<u>-.06</u>	<u>.32<sup>†</sup></u>	.07	.03	.23

Note. Underlined cells indicate a positive correlation was predicted. False discovery rate adjustments were calculated for three families of tests: closely similar tools, broadly similar tools, tool generalist.

<sup>a</sup> Includes variants in which water itself was the mediating object, if orangutans deliberately manipulated water to alter a target: for example, apply water to object to clean it (wash), soak/agitate object in water to extract its contents (suck sugary water from sugarcane). <sup>b</sup> Tools grouped as similar are listed below with their context of usage (water, play, nonwater). Water tools used functionally are italicized. Closely similar: reacher (water—*ruler, rake, br-hook*; nonwater—rake, stick scratcher), probe (water—*probe*; play—probe; nonwater—probe), cup (water—*cup*; play—cup; nonwater—cup), wet (water—*br-dip, wash, play—wet, wiper*), sponge (water—*sponge, soak*; play—sponge), attention (water—*splash*; nonwater—threat), boat (water—*boat, play—boat*), hide (water—*hide, boat, play—boat*). Broadly similar: stick (water—*rake, probe, br-hook, ruler*; play—digger, probe, splasher; nonwater—hitter, swatter, digger, scratcher, rake, cane, threat), cup (water—*cup*; play—cup, cup-scraper; nonwater—cup, cup-scraper), wet/sponge (water—*wash, soak, br-dip, sponge*; play—wet, wiper, sponge; nonwater—wash, wiper).

<sup>†</sup>  $p < .10$ . \*  $p < .05$ . \*\*  $p < .01$ . \*\*\*  $p < .001$  (one-sided tests corrected for false discovery rate).

We assessed behavioral pathways from a cognitive perspective, on the view that (human) actors innovate by applying normal cognitive processes to existing knowledge structures (Ward, 2007). Behavioral pathway findings tie well with findings on great ape cognition. Variants within pathways were commonly ordered from basic generalized to complex differentiated, which resembles acquisition patterns for cognitively governed skills in great apes (Biro et al., 2003; Corp & Byrne, 2002; Inoue-Nakamura & Matsuzawa, 1997; Russon, 2006). Pathways were clearer at lower than higher levels of behavioral organization (i.e., narrow/close vs. broad similarities), suggesting that Kaja rehabilitants favored innovating at specific behavioral levels—in particular, the procedure level in the Byrne et al. (2001) classification. Pathways were

relatively short (max. three precursors), consistent with evidence of great apes' relatively low ceiling of cognitive complexity (Russon, 2004). Both patterns are consistent with evidence that great apes have limited abilities to transfer skills across tasks (Martin-Ordas, Call, & Colmenares, 2008; Povinelli, 2000; Russon et al., 2007).

Pathway findings resemble patterns found in other taxa. Other taxa with multileveled behavior may also preferentially innovate at particular levels; some songbirds, for example, may innovate more commonly in song types (sequences of song elements) than song elements (Marler, 1991; Slater & Lachlan, 2003), and humans more commonly generate innovations from specific than general previous knowledge (Ward, 2007). Behavioral pathways compris-

Table 4  
*Social Influences on Innovating*

Performances			Close association rates		<i>p</i>
			Innovator	Noninnovator	
Behavior	Actor	No. of OU	<i>M (SD)</i>	<i>M (SD)</i>	
Innovation	Innovator	23	.08 (.09)	.04 (.05)	.0343 <sup>a,b</sup>
Immediate precursor	Innovator	23	.18 (.11)	.08 (.08)	.0053 <sup>a,b</sup>
	Noninnovator	16	.08 (.08)	.03 (.05)	.0343 <sup>a,b</sup>
Mundane	Innovator	23	.38 (.20)	.18 (.12)	.0016 <sup>b,c</sup>
	Noninnovator	16	.21 (.14)	.12 (.11)	.070 <sup>b,c</sup>

Note. Performances are classified by behavior (innovation, immediate precursor, other) and actor (innovator, noninnovator, all). Rates represent the proportion of available partners because the number of possible innovator and noninnovator associates varied with actor and performance type. Tests assess innovator—noninnovator differences in association rates; significance levels shown are false discovery rate corrected, treating all tests as one family. OU = orangutan.

<sup>a</sup> Wilcoxon two-sample test, two-sided (direction of difference not predicted). <sup>b</sup> Wilcoxon two-sample test, one-sided (higher association rates predicted for innovators). <sup>c</sup> *p* values for exact test.

Table 5  
*Social Rank and Innovation: Being an Innovator and Total Water Variants*

	Social rank			Total
	High	Mid	Low	
Innovator				
Yes	8	11	4	23
No	5	2	9	16
Total water variants				
High	5	10	5	20
Low	8	3	8	19

Note. Total number of water variants: high (15 to 31), low (4 to 14).

ing sequences of small changes leading to an innovation resemble acquisition patterns for complex skills in several species. In captive chimpanzees, interception emerged via a series of small changes from chasing (Iversen & Matsuzawa, 2003) and their solving the famous out-of-reach-reward task depended on knowing all relevant components (Köhler, 1925). New Caledonia crows' novel tool making and humpback whales' lobtailing also appear to result from multiple-small changes to preexisting skills (Hunt et al., 2007; Hunt & Gray, 2003; Weinrich et al., 1992; Weir & Kacelnik, 2006). Rehabilitants' ecological innovations similarly suggest acquisition by cumulative change to an individual's skills. A clear example is intercept: behavioral pathways likewise suggest intercept was acquired by building on chase and, in addition, chase itself built on deep and deep on basic. Pathways leading to other ecological innovations suggest similar accumulation of small changes (e.g., pull, probe). This may characterize ecological skills in general because, to be effective, they must solve causal tasks.

Table 6  
*Overview of Findings on Innovative Processes in Kaja Rehabilitants' Water Innovations*

Task	Innovation	Change precursor <sup>a</sup>	Contributors to innovating <sup>a</sup>				Social rank <sup>c</sup>
			Transfer	Accident	Independent	Social <sup>b</sup>	
Float item	Intercept	Y	Q	—	Y	—	2
	Pull	Y	—	Q	Y	—	2
	Soak	Y	Y	Q	P	Y	1
Sunk item	Fish	Q	—	Q	Y	NA	1
	Rengas	Y	Q	Q	P	Y	2
	Probe	Y	Y	—	Y, Q	NA	2
Drink	Sand	Y	—	Q	—	Y	2
	Sponge	Y	Y	Q	Y, Q	—	1.5
	Br-dip	Y	Y	—	Y, Q	NA	1
Travel	Ruler	—	—	—	Y, Q	—	1
	Boat	Y	—	Q	Y	Y	2
	Swim	Y	Q	Q	Y	—	2.5
	Br-hook	Y	Y	—	Y	NA	2
Social	Splash	Q	Y	Q	P	Y	2
	Distract	Q	Q	—	—	Y	1
	Hide	Q	Y, Q	Q	P	Y	2.5
	Sex	Q	Q	—	Y	NA	2
Play	Submerge	Y	—	Q	Y, Q	NA	3

Note. Y = yes (statistical); Q = yes (qualitative); P = probably; NA = not applicable; dash = no evidence.

<sup>a</sup> Cells summarize the likelihood that each factor contributed to an innovation. <sup>b</sup> Social: Y = yes (at least twice, innovator had access to social input: i.e., associated closely at innovation or immediate precursor, interacted at innovation performance). <sup>c</sup> Average social rank across innovators for this innovation: 1 (high), 2 (mid), 3 (low).

For social innovations, where effectiveness can be otherwise defined (e.g., effectiveness in some bird songs may depend on differing from competitors), cumulative change may be less relevant (Slater & Lachlan, 2003).

On Kaja, social input relevant to innovating was mostly gained from associates with similar abilities and interests. This is consistent with evidence that rehabilitant orangutans with similar backgrounds and abilities tend to associate preferentially and to adopt similar behaviors, and suggests a cycle wherein similar interests and abilities foster association, which associations in turn enhance shared interests and abilities (Riedler, 2007; Russon & Galdikas, 1995). Social patterns may well be taxon and/or task specific, however, as some evidence suggests (Boogert, Reader, Hoppitt, & Laland, 2008; Hausberger, Richard-Yris, Henry, Lepage, & Schmidt, 1995; Huffman & Hirata, 2003).

## Development

Evidence indicated few developmental effects, probably because the narrow age range on Kaja resulted in relatively homogeneous innovative potential. One of the few examples is that primiparous mothers carrying young infants and facing deep water were the only probe and ruler users, possibly because their changed reproductive status increased their wariness. However, the adolescent age profile itself may have enhanced innovativeness on Kaja. Orangutans disperse from their natal range around adolescence and dispersal may increase innovativeness (Slater & Lachlan, 2003). Correspondingly, adolescent orangutans show qualities linked with high innovativeness: near-adult experience, competence and cognition, risk-taking tendencies, independence, gregariousness, and continuing learning needs (Greenberg, 2003; Russon, 2003a; Simonton, 2003a, 2003b).

Reader and Laland's (2001) finding that adults are the most innovative age class in primates then merits revisiting. It rests on lumping species and immatures (infant, juvenile, adolescent), confounding differences between species and phases of immaturity. Our findings add to evidence that species may differ in the age at which they are most innovative, depending on when and where behavioral variety is most important. Human creativity may have two peaks, young and midadulthood, depending on the problem area (Simonton, 1988). In some songbirds songs are flexible in immaturity but fixed by adulthood whereas in others, and in some cetaceans, they change continually throughout adulthood (Marler, 1991; K. Payne & Payne, 1985; R. B. Payne, 1996; Rendell & Whitehead, 2001; Slater & Lachlan, 2003). Chimpanzees and keas seem most innovative as subadults (Gajdon, 2007; Reader & Laland, 2001). The chimpanzee–orangutan similarity suggests great apes may be most innovative just prior to adulthood.

### Social Rank

Social rank affected innovating but differently than predicted: on Kaja, mid- rather than low-ranking orangutans were the most innovative. This agrees with Reader and Laland's (2001) suggestion that midranking individuals have high innovative potential. Evidence on corvids supports this view (see Greenberg, 2003). Alternatively, rank effects could depend on species dominance patterns or contextual factors. In a group of male starlings, high-rank males first solved novel foraging tasks; subjects were captives, however, so context may have affected rank advantages (Boogert et al., 2008). On Kaja, context probably played a key role. Feeding platforms gave the best access to good food; most were built over water near the shore so water around platforms offered next best access to food, and areas beyond the worst. High-ranking orangutans dominated platforms, so midranking ones probably specialized on water around platforms as their best option, and the low-ranking were relegated to areas beyond.

### Multiple Contributors to Innovating

Our findings indicate multiple events contributed to innovating for all water innovations but ruler. Fourteen innovations were linked with two or three contributors, and three with all four. Our moderate effect sizes for tool use correlations likewise suggest that transfer influenced but did not entirely generate tool innovations. Interplay among multiple contributors may then be typical in orangutan innovating or even necessary for innovative ecological skills or multifunctional behaviors like tool use for social purposes. It can be in humans (Sternberg, 2006).

Other findings on transfer in great apes suggest a kind of interplay potentially involved in Kaja orangutans' innovating. Great apes are considered to have strong potential for transfer, in their capacities for interconnecting different cognitive abilities, insight, analogical reasoning, jumping to higher levels of abstraction, and cognitive generativity (Gibson, 1990; Köhler, 1925; Lethmate, 1982; Parker, 1996; Rumbaugh, Washburn, & Hillix, 1996; Thompson & Oden, 2000). Empirical evidence, however, shows limited transfer (Martin-Ordas et al., 2008; Russon et al., 2007). Kaja rehabilitants showed few links between variants with general similarities and less tool transfer than predicted. They did appear to transfer an old nesting skill from captive to forest life,

however, after social or fortuitous events prompted it (Russon et al., 2007). Some chimpanzees transferred tool expertise only after prompting (Povinelli, 2000), and human innovations are susceptible to priming (Ward, 2007). Langer (1996) proposed that fortuitous co-occurrences of normally unconnected behaviors provide experiential bridges that promote interplay between mental structures in humans, by creating or priming associations. Initial priming might similarly promote transfer in great apes.

We therefore explored phase or stage models of innovating. Our findings on innovative processes are reconstructions that cannot track behavioral change in detail, so we limited consideration to two-phase models of human creativity: generating new behavioral possibilities, then refining or evaluating them and retaining the best (Dennett, 1978; Finke et al., 1992; Gabora, 2002; Simonton, 2003a). The invention/improvisation-innovation distinction common in the nonhuman literature is similar (Reader & Laland 2003; Slater & Lachlan, 2003), although our emphasis here is their connectedness. The first phase may involve low-level associative processes that recognize or generate co-occurrences, and the second, analytical-evaluative processes that identify or manipulate the relations involved (Gabora, 2002). Of the contributors we considered, social input and accidents seem most suited to generating new possibilities and independent working out to refinement and evaluation.

More interesting is that Kaja orangutans' innovating probably involved phase-like interplay among multiple contributors. Where we had several observations of one innovation by one orangutan, these sequences were suggested: accidents then transfer and/or independent practice (submerge, swim, pull, hide, splash, sand), social input then transfer (probe). Sequences of contributors are also described in the acquisition of novel behavior by captive orangutans and some other species (e.g., British tits, keas, New Caledonia crows, humpback whales): Commonly reported are accidents, social input, transfer, or "insight" followed by independent working out (Hinde & Fisher, 1972; Huber & Gajdon, 2006; Lethmate, 1982; Mendes et al., 2007; Sherry & Galef, 1984; Weinrich et al., 2002; Weir & Kacelnik, 2006).

### Conclusions

This study constitutes the first systematic assessment of innovative processes in forest-living orangutans. Findings indicate the same innovative processes proposed elsewhere along with several complexities. In innovating, these rehabilitant orangutans appeared to favor narrowly circumscribed, procedure-level change although innovating at other levels appeared possible. Their innovating appeared to be multidetermined, in that it often involved the coming together of several facilitating factors, and may unfold in phase- or stage-like fashion. All of these patterns are suggested in humans and in some other nonhuman taxa.

Ramsey et al. (2007) argued that, properly designed, field studies of innovations can contribute to inferring innovative processes. The field approach we used suggested innovative processes that are plausible and consistent with relevant findings on cognition and on innovation in other taxa, humans included. We consider that what success we achieved owes partly to extending current prevalence methods for identifying innovations to include suitable parsing rules, levels of task relatedness, and establishing the relevant behavioral repertoire for the study population. All have

parallels in field studies of bird and cetacean song change or experimental studies of their tool innovations. Even with these extensions, however, we had difficulty identifying which of several similarities were significant to an actor and which variants were new (some looked new in one context but proved to be known or very similar in another), so risks of misidentifying innovations remain. Moving ahead requires improving methods to address these problems and undertaking long-term studies. The value of long-term field studies of primate behavior, especially for historical phenomena such as innovating, is amply demonstrated (e.g., [Biro et al., 2003](#); [Boesch, 1995](#); [Huffman & Hirata, 2003](#); [Panger et al., 2002](#)). Multiyear studies of song change in birds and cetaceans then offer valuable methodological suggestions for long-term study of innovation in primates. Greater incorporation of research on human creativity also merits consideration, given the several parallels suggested here.

These findings provided an initial model on which to base future work and suggest several issues worth pursuing. If rearing as an orphan increased innovativeness in these rehabilitants, then orangutans may be able to learn to innovate. This has been shown in humans ([Sternberg, 2006](#)) but is little studied in nonhuman species ([Reader, 2007](#)), although similar hints in other species suggest it merits attention ([Greenberg, 2003](#); [Pryor, Haag, & O'Reilly, 1969](#)). Innovating may unfold differently for ecological and social innovations, given the different contingencies involved, so comparing the two pathways could be important. The multiprecursor sequences we identified for complex ecological skills indicated specialists; in unusual foraging techniques also have been reported in bottlenose dolphins ([Mann & Sargeant, 2003](#)). This would put a premium on recognizing others' competencies—in some sense, knowing what others know. Recognizing others' competencies, in the form of selective attention to or association with experts, was evident in Kaja orangutans and some other taxa ([Otoni et al., 2005](#); [R. B. Payne, 1985](#)); other forms of knowing what others know have been shown experimentally in chimpanzees ([Kaminski, Call, & Tomasello, 2008](#)). The field findings then suggest one basis for this social-cognitive ability. Finally, Kaja rehabilitants' innovativeness, although atypical, nonetheless demonstrates the exceptional behavioral flexibility of which orangutans are capable. Highly innovative species are especially successful in invading novel environments ([Sol, Timmermans, & Lefebvre, 2002](#)). For orangutans, high-innovative potential is then a double-edged sword. They are endangered largely because humans are rapidly transforming their habitat, so although their flexibility facilitates adjustment to new forests it also facilitates crop raiding. Applying innovation findings to conservation then offers great practical value.

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## Appendix A

### Retrieve Items From Water

Behavioral pathways for retrieving items from water, as a broadly defined task. Column headers: orangutan (two-letter name code), variant label (number of variant users). Cells: shaded = user; unshaded = nonuser.

## Appendix B

### Water Play

Behavioral pathways for water play. Column headers: orangutan (two-letter name code), variant label (number of variant users). Cells: shaded = user; unshaded = nonuser.

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