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Direct touches to clear barriers: Developmental sensitivity of a new measure of the production of ineffective responses in infancy

Julia S. Noland, Ph.D. and **Nikita P. Rodrigues**

Vanderbilt Kennedy Center Department of Psychology and Human Development Vanderbilt University Nashville, TN

Abstract

Current interpretation of the object retrieval task (Diamond, 1990) as an infant assessment of response inhibition requires evidence that younger infants make more ineffective attempts to retrieve toys through clear barriers. On two 30-second trials, infants (9- or 11-months of age) saw an inaccessible toy in the front or back of a clear box. The location of the infants touches corresponded with the toy's location and, on the second trial, the younger infants touched the box more. In an analogous task, non-human primates with orbital-frontal, but not dorsa-lateral, lesions also made ineffective barrier touches. The current developmental decreases in barrier touches may selectively tap developmental increases in inhibitory control supported by the developing orbital-frontal cortex.

Younger infants have a long-established difficulty detouring around clear immobile barriers and Adele Diamond recognized the similarity of this phenomenon with the difficulties lesions of the frontal cortex produce in non-human primates (Diamond, 1990). She developed the object retrieval task as an executive functioning (EF) assessment and found it sensitive to metabolic risks to frontal functioning (Diamond, Prevor, Callender, & Druin, 1997). According to the neuropsychological framework underlying the task, older infants are more effective because their cognitive abilities allow them to resolve the conflict between effective (detouring around the barrier) and ineffective behaviors (perseverating in attempting to reach direction through the barrier). The findings that older infants spend less time touching clear barriers (Lockman & Adams, 2001) and retrieve toys faster (Diamond & Gilbert, 1989) supports this EF interpretation of the challenge presented by clear barriers. Within the EF interpretation, older infants are more successful at resolving the response conflict because of more developed working memory (Stedron, Sahni, & Munakata, 2005) or more developed working memory and response inhibition (Diamond, 1991).

An alternative interpretation of the barrier touches is that they are not aimed at the toy directly, but are attempts to gather visuomotor information about the barrier. This would enable the infant to find the edge of the barrier and thus the path for detouring to the toy. In the current study, we presented trials with the toy placed in the front half of the box (near the infant) and trials with the toy placed at the back of the box (far from the infant). If barrier touches are attempts to find an opening, then the location of the toy should have no effect. However, if the touches are attempts to retrieve the toy through the clear barrier, then infants should touch the half of the box in which the toy is placed.

We also investigated a weakness to the claim that older infants touch the clear barrier less because they have successfully resolved the response conflict generated by clear barriers (Diamond, 1990). As yet, response conflict has not been an inescapable component of the task. In our review of studies reporting a developmental advantage in retrieval from behind a clear barrier, the configurations utilized have consistently allowed the infants to reposition themselves to obtain an accessible view of the toy. In other words, they could move their upper torso, look at the toy around the edge of the barrier and reach through directly for the toy.

Older infants may produce fewer clear barrier touches simply because they were quicker to attain an accessible view of the toy and, thus, escape from the potential response conflict demands of the task altogether. Thus a developmental difference in motor strategy may account for performance advantages previously reported with clear barrier tasks. In the current study, the clear box was turned so that the only opening faced 180 degrees away from the infant. The infants were not able to retrieve, or even view, the toy through the opening. The EF interpretation of barrier touches is that they are ineffective attempts to retrieve the toy. If this is correct, they should be made less frequently by older infants even in the “no opening” version of the task wherein a more effective motor strategy will not allow the older infants to remove themselves from the response conflict.

In summary, we sought to understand the developmental challenge presented by clear barriers by testing the hypotheses that: 1) infants would touch the half of the clear box where the toy was located; and 2) that older infants would continue to produce fewer barrier touches even when they could not maneuver themselves out of the response conflict situation.

Two separate groups of infants participated: 9-month-olds [$n=27$, mean age= 9 months 5 days ($SD=12$ days)] and 11-month olds [$n=11$, mean age=11 months 0 days ($SD=11$ days)]. The ratio of males and females was equivalent: males were 44% of the 9-month group and 45% of the 11-month group. The data of one additional infant was unusable due to technical problems. There are uneven numbers of participants in the two age groups owing to the convenience sampling method employed. It was not feasible to recruit families to come in solely to participate in the current task that lasted less than 3 minutes. We gave the current task to all infants in the appropriate age ranges coming into the lab to participate in an ongoing study. The current task was given first.

A clear plastic box (top, 11.4 cm by 11.4 cm, and three 6.35 cm high sides) was placed on the testing table such that the infant was presented with a solid top, front, as well as two solid sides. The only opening faced toward the examiner and was positioned 180 degrees away from the infant. The front of the box remained 11.4 cm from the front edge of the testing platform. The infants reached for a yellow plastic duck. An alternative toy of similar size was employed if the infant was not interested in the duck. This substitution took place before the first test trial and the same toy was always used for both test trials. An alternative toy was employed for 19% of 9 month olds and 18% of 11 month olds.

The infant sat across from the examiner in a highchair or, if fussy, on the parent's lap. There was a warm-up period that allowed the infant to become familiar with and engaged with reaching for the toy on the testing table. After the warm-up, the infants were presented with two consecutive test trials that were separated by a brief opportunity to play with the toy. All infants received one *Near* and one *Far* test trial. The order of the *Near* and *Far* test trials varied randomly and did not differ between the age groups (Chi-square = .06, $p < .8$). Test trials began with the experimenter placing the box in position and then the toy into the box through its open back panel. For the *Near* trials, the toy was in contact with the inside front

panel of the box. For the *Far* trials, the toy was at the midpoint of the box, roughly 6 cm from the inside front panel. The examiner then placed both hands on the back of the box and held it in place for the 30-second duration of the test trial.

Videotapes of the testing were digitized and then coded frame-by-frame by assistants blind to toy location. The coders marked periods when the infants were simultaneously looking and touching the box. These attentive touch periods were the only ones coded and, heretofore, are simply referred to as barrier touching. If any part of the more active hand was on the back half of the box the location of touching was classified as back of the box. The 30-second trial length was confirmed during post-hoc coding. For reliability, two assistants coded both of the test trials of 18% infants ($n=14$ trials). The coders' sums for total touching time were significantly correlated, $r(1,14)=.88$, $p<.0001$.

As expected, the toy's location affected the half of the box that the infant touched. Time spent touching the front of the box touches was higher on *Near* trials when the toy was in the front of the box [mean 12.3s ($SD=5.45$)] than on *Far* trials [mean 8.19s ($SD=5.02$), $t(1,37)=4.17$, $p<.001$]. Similarly, time spent touching the back of the box was higher on *Far* trials [mean 2.74s ($SD=3.73$)] than on *Near* trials [mean .76s ($SD=1.26$ s), $t(1,37)=3.42$, $p<.01$].

For the developmental analysis, the two age groups were compared on time touching the box, regardless of location. The 30-second duration of each trial was divided into 10 bins of 3 seconds each. With a mixed model analysis solving for fixed effects on touching time within each bin, each trial was effectively a set of 10 sequential 3-second assessments. The division of each trial into 10 bins allowed us to reduce error variance by accounting for the common decrease of touching across the 30-second trials. The mixed procedure is similar to a repeated measure ANOVA comparison and main effects of age group, (9 vs. 11 months), trial number (first vs. second trial) and the interaction of age group and trial number were tested. There was no main effect of age group effect ($F(1,702)=.42$, $p<.42$), but a significant effect of trial number ($F(1,720)=30.79$, $p<.0001$), and a significant interaction between age group and bin number ($F(1,304)=3.69$, $p<.06$). Summing across the bins Trial 1, 9-month-old infants touched the barrier a mean of 14.62 s ($SD=5.9$) and the 11-month-olds touched it a mean of 12.12 seconds ($SD=5.63$). On Trial 2, the 9-month-old infants touched the barrier a mean of 10.66 ($SD=5.8$) and the 11-month-olds touched it a mean of 8.76 seconds ($SD=4.1$). As a follow-up to the significant interaction of age group and trial group, we repeated the mixed model for the two trials separately, substituting bin number for trial number. For the first trial, neither of the main effects (age group, bin number) nor the age group by bin number interaction was statistically significant at the $p<.05$ level. As can be seen in Figure 1, on the second trial, there was a significant age group effect ($F(1,340)=12.78$, $p<.001$), a significant effect of bin number ($F(1,340)=7.86$, $p<.01$), and a significant interaction between age group and bin number ($F(1,340)=5.62$, $p<.02$). These effects all remained statistically significant when the model was rerun with a term for toy position (*Near*, *Far*). The younger infants touched the barrier more overall and their touch production only dropped late in the trial.

These findings support the response conflict framework that has guided use of the clear barrier phenomena as an EF assessment. We varied the location of the toy across trials and found a corresponding change in the location of barrier touches. This correspondence would not have occurred if these touches were merely attempts to find the opening of the box. Thus, the current study reinforces the claim that clear barrier touches are ineffective attempts to retrieve the object through the barrier rather than attempts to gain the opening.

Older infants spent less of the second trial touching the clear barrier relative to younger infants. Thus, the previously reported age differences in barrier touches persisted in the

current task configuration, where infants were prevented from escaping the response conflict situation. The “no opening” clear box task introduced in the current study complements the original object retrieval task as a more cognitively specific variation. Working memory allows for maintaining strong representations that specifically support the goal-compatible response (Munakata, 1998). Although this type of working memory certainly would aid the resolution of response conflicts in the traditional version of the object retrieval task (Diamond, 1991), it would do little to reduce ineffective behavior when, as in the current task, there is no specific effective response to be made.

An advantage of the response competition framework to the interpretation of both the original object retrieval task and the current findings is that the cognitive mechanisms targeted have established neurological underpinnings. The current “no opening” task is similar to the most difficult trials used in an analogue task with non-human primates (Wallis, Dias, Robbins, & Roberts, 2001). In this task, the angle of the clear barrier was adjusted across trials. On trials where obtaining an accessible view of the reward was nearly impossible the animals with orbital frontal lesions made hundreds of ineffective direct reaches for the reward. They had no deficit, however, learning an opaque barrier version of the task. In contrast, animals with lesions to the part of frontal cortex which support working memory (dorsal-lateral prefrontal) readily learned to detour around the clear barrier but had difficulty transferring this learning to the opaque barrier task. Taking into account established functions of the orbital-frontal cortex, the authors interpret this pattern as suggesting the orbital frontal lesions caused either: 1) a failure to inhibit ineffective responses and/or 2) a failure to learn that barrier reaches are ineffective.

In this context, the current finding that younger infants may produce more barrier touches on their second trials is attributable to their less developed orbital-frontal cortex and the resultant poor inhibition of ineffective responses (or poor learning of the ineffectiveness of such touches). This eliminates a possibility left open by previous research that developmental decreases in human infant's production of ineffective responses could be entirely attributable to developmental increases in dorsal-lateral support for working memory/ planning.

In the current study, we have introduced an “inaccessible object” version of the traditional object retrieval task that may more specifically tap response inhibition. The task prevents infants from using working memory and planning abilities to avoid the response conflict, as they can on the object retrieval task. As a result this task is more directly comparable to trials in which non-human primates with disrupted orbital frontal functioning make the most ineffective responses. The current study introduces a 3-minute task could be given as part of a complementary battery that includes tasks tapping other EF abilities such as planning and working memory.

The reported cross-sectional developmental sensitivity is of this “inaccessible object” task is important for its potential clinical utility with at-risk infants. Unlike low-risk volunteers that can be recruited on the basis of their willingness to be tracked longitudinally across the relevant months, infants with suspected deficits in prefrontal functioning may only be available for a single-assessment during the relevant months. In sum, the current “inaccessible object” task complements the object retrieval task and other executive functioning assessments by more specifically accessing response inhibition.

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Figure 1.
Barrier touching across Trial 2