Hide and Seek: The Theory of Mind of Visual Concealment and Search

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Giles M. Anderson[1]*, Tom Foulsham*[3]*, Eleni Nasiopoulos*[2]*, Craig S. Chapman*[4]*, Alan Kingstone*[2]

[1]*Oxford Brookes University,* [2]*University of British Columbia,* [3]*University of Essex,* [4]*University of Alberta*

Abstract

Researchers have investigated visual search behaviour for almost a century. During that time few studies have examined the cognitive processes involved in *hiding* items rather than *finding* them. To investigate this, we developed a paradigm that allowed participants to indicate where they would hide (or find) an item that was to be found (or hidden) by a friend or a foe. For friends, more than foes, participants selected (i) the popout item in the display and (ii) when the display was homogenous they selected nearby and corner items. These behaviours held for hiding and finding, although hide and find behaviours were not identical. For popout displays decision time was unusually long when hiding an item from a foe. These data converge on the conclusion that the principles of search and concealment are similar, but not the same. They also suggest that this paradigm will provide researchers a powerful method for investigating theory of mind in adults.

Many studies have examined search for visual targets when they are hidden in plain sight amidst distractor items (see Nakayama & Martini, 2011, for a review). This research has focused almost exclusively on how search performance is influenced by the visual features of either the target or the distractors (e.g., their saliency, Anderson, Heinke, & Humphreys, 2010) or the relationship between the two (e.g., their visual similarity, Duncan & Humphreys, 1992). Little consideration has been given to the cognitive processes involved in hiding an item. Indeed, researchers have overlooked the idea that, in combination, the study of hiding and finding may create a methodology for investigating 'theory of mind' in adults. For example, one can ask if, and how, one's hiding behaviour is affected by who one believes will be doing the searching, and conversely, if, and how, one's search behaviour is affected by who one believes has done the hiding.

The present study explores these lines by testing two questions: (1) Are hiding and finding linked, and if so, can the well-established principles of search be extended to the development of a theory of visual concealment? and (2) Can coupling hiding and finding provide a crucible for the manipulation and exploration of theory of mind? While little previous work exists on these questions, a handful of relevant studies exist, which we briefly review below.

Of relevance to our first question, Smilek et al. (2009) investigated whether individuals' intuition about hiding items matched those influencing search difficulty. Observers arranged an assortment of items so that a target, placed in plain sight, was easy or hard to find amongst distractor items. New observers searched for the target amongst the constructed displays. Comparisons indicated that a target was found more quickly with 'easy' compared to 'hard' search displays, as assigned by the initial observers. These data suggest that the factors considered relevant by individuals when hiding an item match those for finding an item, i.e., the processes underpinning hiding and finding are similar.

Nonetheless, differences between hiding and finding have been observed in more complex environments (Talbot et al., 2009; Legge et al., 2012). Talbot et al. asked participants to conceal or find objects in different opaque bins distributed in a room. The first three positions selected for both hide and seek conditions were assessed. Objects were hidden in more dispersed positions, farther away than the place of origin, than those selected when searching. The wider spread for hide locations was amplified when the hiding task was undertaken *after* the search task, indicating that people's initial intuitions about hiding were modified after experience with search, as opposed to the two processes naturally tapping into the same strategies.

That hide and find strategies differ suggests that one's belief in the intents and knowledge of others (i.e., their 'theory of mind') may be critical to hiding and finding behaviour, i.e., the way one hides or searches for an object may be affected by *who* one believes is doing the hiding or doing the finding. Thus we hypothesized that a hide-find paradigm may represent a new opportunity for researchers to manipulate and explore theory of mind.

The visual environment itself may also be a key factor. Legge et al. (2012) replicated Talbot et al. (2009) but required individuals to hide and find items in unevenly shaped rooms with darkened areas and windows. The environment interacted differently with hide and find behaviours. When hiding, participants were less likely to place items near windows, though window position had no effect on where people searched. Conversely when searching, participants were less likely to look for items in dark areas, though room luminance had no effect on where items were hidden.

The current study investigated if, and how, changes in the visual environment and one's knowledge about the hider or finder, affects behaviour. We exchanged the uncontrolled and complex visual and behavioural environments used by Talbot and Legge, for the controlled setting of classic search displays: pop-out displays (one item carries a unique feature) and homogeneous displays (all items are the same). This enabled the manipulation of the complexity of the visual world within which hiding and finding would occur, and eliminate the confounds that exist between behaviour and vision when visual changes are introduce by locomotion in a real or virtual environment. Further, and uniquely, we manipulated the participant's conceptualization of the hider or the finder by instructing participants that the person who would be looking for their hidden object, or who had hidden the object that they were now expected to find, was either a 'friend' or a 'foe'. We anticipated this would affect the perceived ease of the hide and find conditions (e.g., one might place a house key for a friend in a concealed location that will be easy to discover) and introduce a factor that directly manipulates theory of mind.

In summary, our study set out to examine if search and concealment engage the same or different cognitive processes, and if our hide-find paradigm can be used to study theory of mind. We explored these issues by manipulating the visual environment for hiding and finding and varying who participants believed the hider or finder was. If changes in the visual environment and/or a participant's conceptualization of the hider or finder (friend or foe) has the same impact on search and concealment behaviour, then the evidence will be that the two behaviours reflect the same underlying processes (Smilek et al. 2009). A significant change in search and concealment behaviour would suggest a very different conclusion. Similarly, if the attribution of the hider and finder as friend or foe has a regular and robust effect on hide and seek behaviour (e.g., behavioural changes cannot be explained entirely by changes in the visual environment), our hide-find paradigm will be an effective tool for investigating theory of mind.

Method

Participants

Thirty-two UBC undergraduates (mean of 21.87) took part for either course credit or money. Four were male.

Design

There were two within-subjects independent variables: partner type (friend or foe) and display type (pop-out or uniform); and one between-subjects manipulation: task type (hide or seek).

Apparatus

Stimuli were projected by a Dell M410HD projector attached to a Windows 7 PC running MATLAB (using Psychtoolbox Version 3) onto a white tabletop. The projected image of a 1024x768 pixel resolution was 800mmx600mm. An Optitrack system recorded the time and location of participants' movements via a marker on the index finger.

Stimuli

Participants viewed a projected image of a 4x4 grid of white boxes (each box 94mmx94mm) on a grey background. Within these squares, blue or green, horizontal or vertical bars were presented, each measuring 62.5mmx15.63mm. A white start bar (78mmx800mm) was presented below the grid (see Fig. 1).

Procedure

Participants were randomly split into two groups, resulting in 17 performing the hide task and 15 participants performing the find task (pilot work confirmed these group sizes yielded replicable effects). Participants sat in front of a table on which the display was projected. Instructions varied depending on task type (hide vs. seek) and the identity of the partner (e.g., whether they were hiding or finding for foe or a friend), as outlined in Appendix 1. In the hide condition, participants were told to select a location to conceal an item so that a friend could find it, or a foe could not find it. In the seek condition, participants were told to select a location where they would look for an object hidden by a friend or foe. Participants started each trial with their index finger on the start bar at the bottom of the screen with no items presented in the grid (see Fig. 1a). The start bar indicated whether the trial involved a friend or foe. Once participants had placed their finger in the start bar for a randomized duration between 1000ms to 2000ms, a display of 16 items was presented (pop-out or uniform, see Figs 1b-1d, for examples). On uniform displays all items were the same; on pop-out displays one item differed in either colour or orientation.

There were 12 blocks with 40 randomly ordered trials. Each block contained eight uniform trials (distributed evenly between the green/blue and vertical/horizontal items), 16 colour pop-out displays (across both orientations), and 16 orientation pop-out displays (across both colours). On pop-out trials, the unique item appeared in each of the 16 possible locations on the table, once per block. Participants undertook six complete blocks with the same type of partner (friend or foe) before reversing the partner (order was counterbalanced). The item selected by the participant was recorded as was the time it took for this selection to be completed.

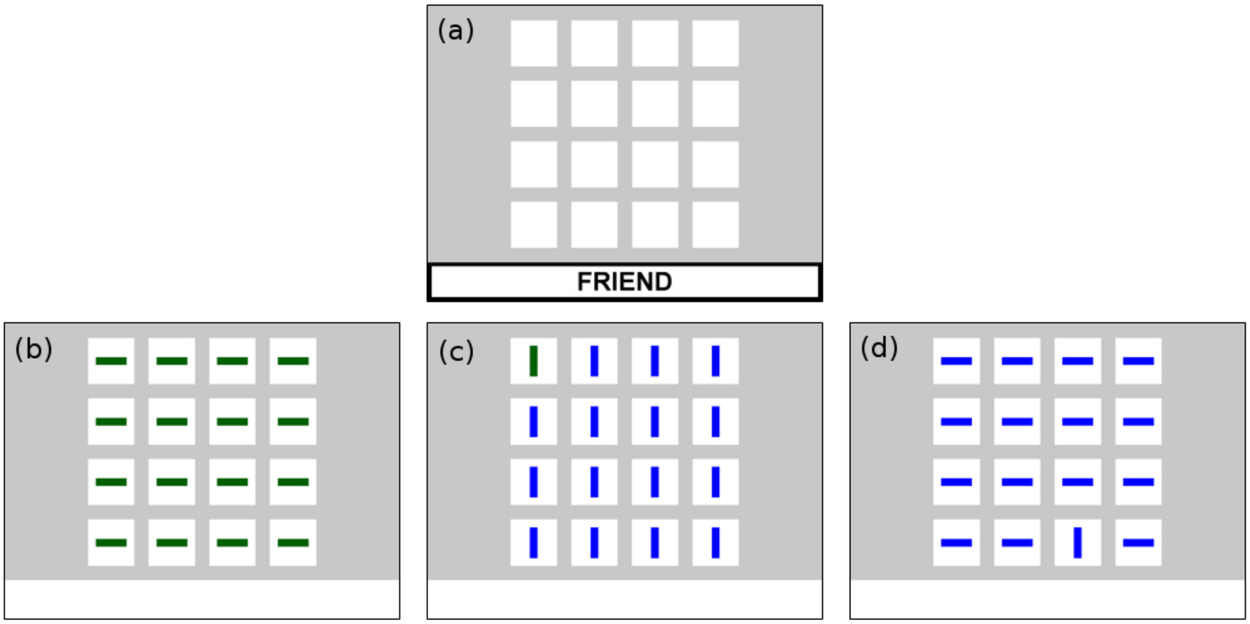

Figure 1. Example displays: (a) pre-trial indication as to the nature of the partner on the upcoming trial, (b) uniform display, (c) colour pop-out, (d) orientation pop-out. Other colour and orientation combinations were also displayed.

Results

Position selection and timing data were analysed separately, with the former analysis based on the normalized frequency data. All ANOVAs report the partial η^2 statistic which describes the proportion of total variability attributable to the particular factor (Olejnik & Algina, 2003). Huynh-Feldt adjustments were used on probabilities where necessary and all *post hoc* pair-wise comparisons included Bonferroni adjustments and were measured as significant at the $p<.05$ level.

Pop-out displays: How often do hiders and seekers select the unique item?

To investigate whether selection is biased towards visually unique items we analysed pop-out trials[1] calculating the relative frequency with which the unique item was selected. The data were split by task type (hide or seek), and partner type (friend or foe). Group means are shown in Figure 2.

[1] No difference was evident between colour and orientation pop-out displays, so data were averaged across conditions.

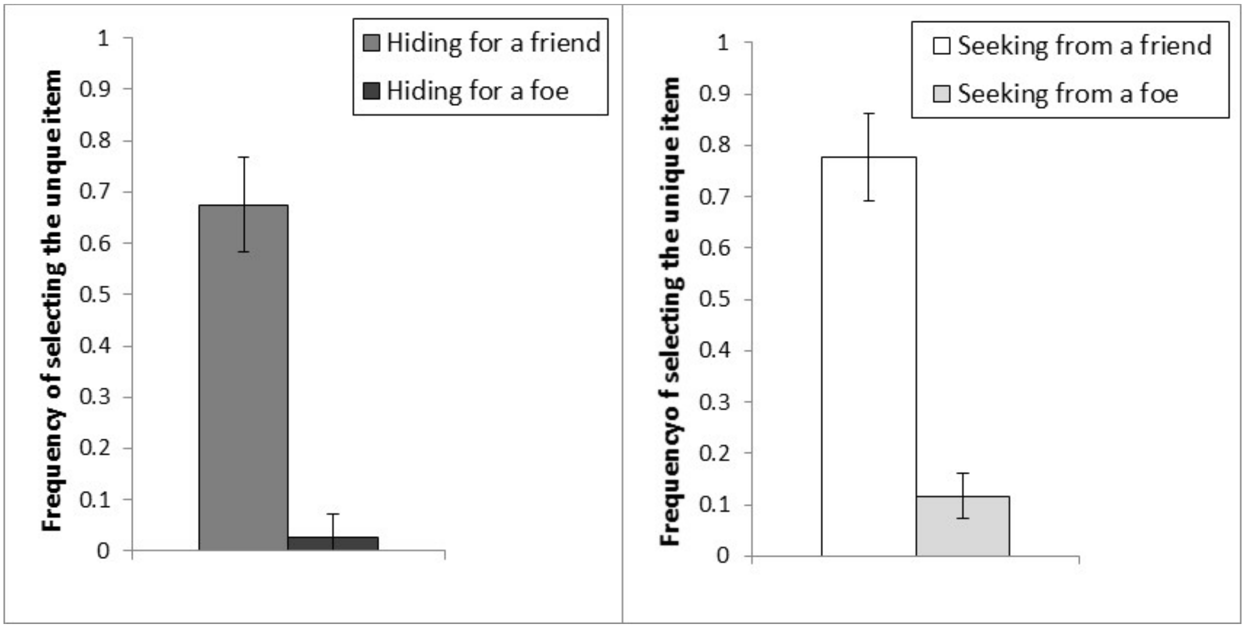

Figure 2. Mean relative frequency with which the unique item was selected (+/- one standard error), split by type of partner (friend, foe), and task type (hiding vs. seeking).

There was a main effect of partner type ($F(1,30)=87.187, p<.001$, partial $\eta^2=.744$). The unique item was selected more frequently on friend trials compared to foe trials (.726 vs. .071). No other effects were significant (all ps>.1).

Homogeneous displays: Are some spatial positions selected more often than others?

To investigate item selection in the absence of visual biases, we analysed which items were selected on homogeneous displays.

Near vs. far

Reaching for closer items required less effort and energy than reaching for items at the back of the display. Would such ‘embodied’ considerations have an impact on the locations selected when hiding and finding for a friend or a foe?

We collapsed item selection across the four items in each row, collapsing further the top two rows and bottom two rows[2]. Data are shown in Fig. 3, from which an overall bias is clear towards participants selecting items closer to themselves. One-sample t-tests indicated the relative frequencies of selecting bottom items were above chance (.5) for all conditions (all ps<.01). A mixed-design, two-factor ANOVA (partner x task type) revealed a main effect of partner type $F(1,30)=4.741, p=.037$, partial $\eta^2=.136$). Participants were more likely to select items closer to themselves on friend compared to foe trials (.836 vs. .704). No other effects were significant (all ps>.4).

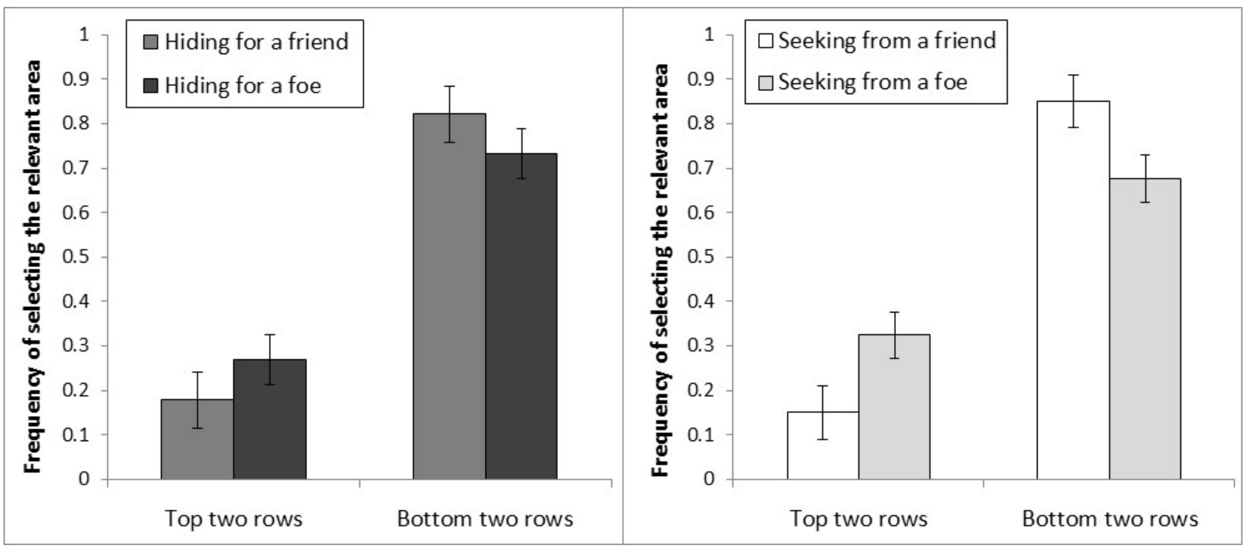

Figure 3. The relative frequency with which the top and bottom two rows were selected on homogeneous displays, split by partner type (friend, foe), and task type (hiding vs. seeking).

Centre vs. corners

Past studies have revealed a tendency to attend, look and reach to the middle of displays (e.g., Prime and Marotta, 2013). We compared the number of times the centre four items were

[2] Frequency data for all position points are available in Appendix 2.

chosen with the number of times the four corner items were chosen (see Fig. 4). A three-factor ANOVA (task type, partner type, item position) indicated main effects of item position (centre vs. corner: $F(1,30)=9.875, p=.004$, partial $\eta^2=.248$), partner type (friend vs. foe: $F(1,30)=4.535, p=.042$, partial $\eta^2=.131$), and task type (hide vs. seek: $F(1,30)=5.742, p=.023$, partial $\eta^2=.161$). Items in the corner were more likely to be selected than central items (.352 vs. .189), while selection of both type of items was increased on friend compared with foe trials (.316 vs. .225), and increased on hide compared with seek trials (.302 vs. .239). There was also a partner type x item position interaction ($F(1,30)=29.209, p<.001$, partial $\eta^2=.493$). Corner items were more likely to be chosen on friend compared with foe trials (a difference of .329, $p<.001$), while central items were more likely to be chosen on foe rather than friend trials (a difference of .165, $p=.002$). No other effects were significant (all ps>.05).

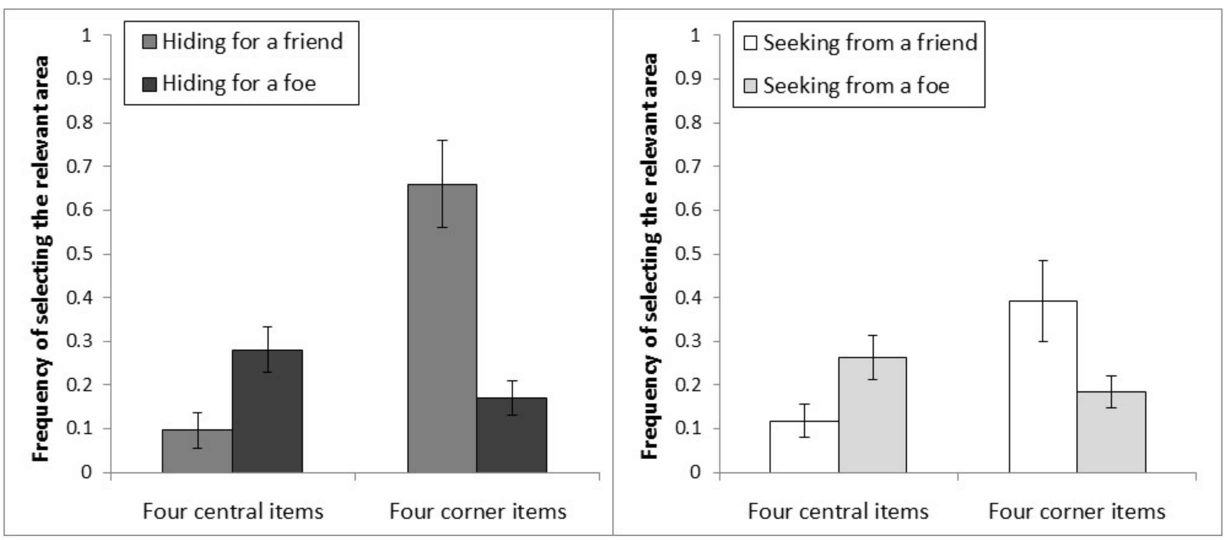

Figure 4. The relative frequency with which centre and corner items were selected on homogeneous displays, split by partner type (friend, foe), and task type (hiding vs. seeking).

Does the time taken to hide and seek differ?

The time from the start of the trial until participants selected an item was recorded (completion time). Median completion times were calculated for each participant within each condition (display type, type of partner) and split by task type (hiding, seeking). Group means are shown in Fig. 5.

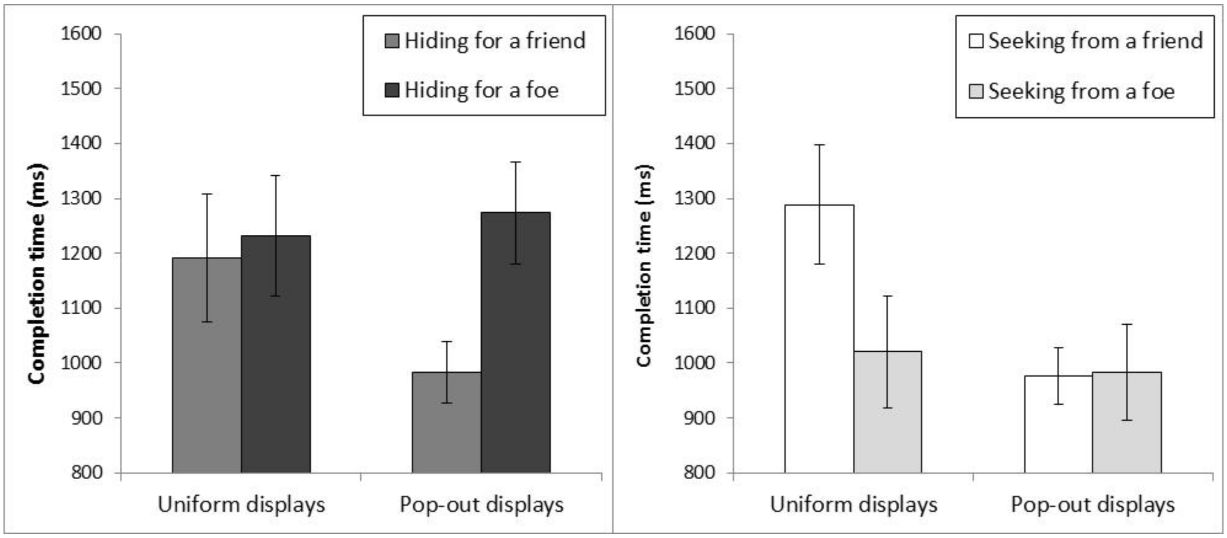

Figure 5. Mean of median completion times (+/-1 one standard error), split by display type (uniform, pop-out), partner type (friend, foe), and task type (hiding vs. seeking).

Uniform displays. On trials with no unique items, there was a borderline interaction between partner type and task type (F(1,30)=3.941,p=.056, partial η^2=.116). When hiding, there was no difference between friend and foe (p=.719), while when seeking there was (a difference of 268ms, p=.017). No other main effects or comparisons were significant (all ps>.1).

Pop-out displays. There was a main effect of partner type (F(1,30)=8.124,p=.009, partial η^2=.213). Reponses for foes were longer than for friends (1129ms vs. 980ms). There was also an interaction (task type x partner: F(1,30)=7.299,p=.011, partial η^2=.196). The interaction was driven by hiding a target for a foe taking far longer both than hiding a target for a friend (290ms, p=.001) and seeking an item hidden by a foe (a difference of 290ms, p=.031). No other comparison reached significance (all ps>.9).

Discussion

We addressed two broad theoretical issues: (1) Do the principles of search apply also to concealment? and (2) Does a hide-find paradigm allow for one to examine theory of mind in adults?

On the first count the data reveal that the underlying cognitive processes for search are similar but not the same as for concealment. When presented with popout displays, participants in both the hide and find groups selected the unique item for friends but not for foes. In other words, they opted for the item that is known to attract attention automatically only when they understood that the hider or the finder was a friend. We propose that this reflects the fact that participants appreciate that a friend would conceal an object or search for an item at a location that attracts attention. This is similar to the finding that participants infer what is salient to another person when interpreting language (see Clark, Shreuder, & Buttrick, 1983). Importantly, hide and find behaviours also diverge in at least one respect. When there is a unique pop-out item, participants take longer to decide where to hide an item from a foe than to search for a target hidden by a foe (see Fig. 5).

This latter finding points to the conclusion that our hide-find paradigm engages processes relating to theory of mind. We propose that participants, when faced with a visual item that pops-out, accurately intuit that a searcher will be attracted to the pop-out location. A hider thus needs to 'simulate' where a foe's attention will go next after the pop-out location, and hide it elsewhere. This process is likely to be time consuming, and risks becoming a recursive problem akin to the 'prisoner's dilemma'[3]. This explains why decision time is delayed. In contrast, when searching for a target hidden by a foe in such a situation, the task of selecting the target location will quickly be learned to be relatively insurmountable (15 possible locations if the pop-out location is excluded from consideration) and a rapid guess is as likely to succeed as a slow and considered response.

In short, our study suggests not only that hiding and finding engage different cognitive processes but it raises the possibility that the hide-find paradigm can serve as a tool for examining theory of mind. Indeed, the theory of mind in our study extends beyond the visual to the embodied environment. When displays were uniform, participants in both the hide and find groups selected items that were physically closer, suggesting that embodied cues were used to determine an easy (friend) and hard (foe) search. Participants also selected corner positions on friend trials and more central items for foe trials. The placing of easy targets in corner positions of the display and hard targets more centrally converges with the notion that edges are a salient feature that supports pop-out in a variety of domains (e.g., texture, motion, disparity), whereas a target is well camouflaged when surrounded by like items. Our finding that participants have accurate and natural intuitions of these facts dovetails with Smilek et al. (2009).

We have introduced a novel hide-find paradigm to study theory of mind in general and the cognitive processes of hiding and finding in particular. This paradigm provides the opportunity to answer a wide range of research questions of both empirical and theoretical import. Some issues are natural follow-ups to the present investigation. Only homogenous and pop-out visual situations have been compared. What happens in more realistic, non-uniform and spatially jumbled displays, with different luminance values scattered somewhat randomly across

[3] We would like to thank an anonymous reviewer for raising this possibility.

the visual field (e.g., Legge et al. 2012), or feedback regarding the success of one's behaviour? The 'mind game' underlying our deceptively simple paradigm is therefore not only of theoretical interest itself, but is an invaluable starting point for an exciting array of future research.

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Appendix 1

Task	Partner	Instruction
Hide	Friend	You want to hide an object under one of the squares so someone WILL find it; much like you might hide a spare key outside your home so someone can find it easily. Touch the square where you would hide the item.
Hide	Foe	You want to hide an object under one of the squares so someone WILL NOT find it; much like you might hide a spare key outside your home so no one can find it easily. Touch the square where you would hide the item.
Seek	Friend	An object has been hidden under one of the squares so you WILL find it; much like a person might hide a spare key outside their home so someone can find it easily. Touch the square where you would find the item.
Seek	Foe	An object has been hidden under one of the squares so you WILL NOT find it; much like a person might hide a spare key outside their home so no one can find it easily. Touch the square where you would find the item.

Table 1. Instructions split by task type and type of partner.

Appendix 2

	Left	Middle left	Middle right	Right
Top	0.101	0.003	0.011	0.017
Top middle	0.014	0.015	0.011	0.006
Bottom middle	0.008	0.04	0.029	0.071
Bottom middle	0.126	0.053	0.079	0.415

Figure 1. Relative selection frequencies for each grid of the display in the homogeneous condition when participants were hiding an item for a friend.

	Left	Middle left	Middle right	Right
Top	0.016	0.011	0.015	0.04
Top middle	0.013	0.016	0.022	0.016
Bottom middle	0.013	0.037	0.043	0.039
Bottom middle	0.178	0.211	0.172	0.158

Figure 2. Relative selection frequencies for each grid of the display in the homogeneous condition when participants were finding an item hidden by a friend.

	Left	Middle left	Middle right	Right
Top	0.008	0.013	0.018	0.008
Top middle	0.053	0.056	0.07	0.043
Bottom middle	0.15	0.053	0.103	0.085
Bottom middle	0.062	0.093	0.094	0.09

Figure 3. Relative selection frequencies for each grid of the display in the homogeneous condition when participants were hiding an item for a foe.

	Left	Middle left	Middle right	Right
Top	0.017	0.028	0.045	0.018
Top middle	0.036	0.053	0.072	0.054
Bottom middle	0.031	0.048	0.089	0.065
Bottom middle	0.043	0.107	0.188	0.107

Figure 4. Relative selection frequencies for each grid of the display in the homogeneous condition when participants were finding an item hidden by a foe.

Homogeneous displays: Are some spatial positions selected more often than others?

Centre vs. corner, near vs. far. When one analyses the selection of corner items on uniform displays with item distance as an added factor (top row vs. bottom row), then the times it was significant as a main effect, or as an interaction, are the following.

A four-factor ANOVA (task type, partner type, item distance, item centrality) indicated a main effect of item distance (near vs. far: $F(1,30)=80.504$, $p<.001$, PES=.729). Closest items were selected more frequently than items distant to participants (.272 vs. .046). There was an item distance x partner type interaction ($F(1,30)=7.064$, $p=.012$, PES=.191), driven by increased selection of items in the near row on friend compared to foe trials (a difference of .152, $p<.001$). The corresponding difference in the farthest row did not approach significance (a difference of .014, $p=.54$). There was also an item distance x item centrality x task type interaction ($F(1,30)=4.997$, $p=.033$, PES=.143). Participants were more likely to seek than hide items in near central positions (a difference of .178, $p=.003$), while items were more likely to be hidden in near corner than near central positions (a difference of .188, $p=.014$). No other comparisons reached significance (all $ps>.1$).