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The progressive elimination task in dogs (*Canis familiaris*): The case of divergence

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Empirical evidence revealed that in a multi-choice task animals choose as the next target the farthest one, which has been referred to as the principle of maximal divergence (MD; Lachman & Brown, 1957). Whereas researchers proposed that MD should facilitate visual discrimination, MD could also be the outcome of a flexibility/cognitive overload trade-off. The present study aimed at contrasting these two hypotheses. Domestic dogs (*Canis familiaris*) were administered a progressive elimination task in which they had to visit and deplete either 3 or 4 baited sites. They were brought back to the starting point after each visit. When being administered a 4-choice task (Experiment 1) with either low but constant angular deviation or mixed (i.e., large and low) angular deviation between adjacent targets, the dogs first chose an inner target (e.g., right inner target) and the opposite outer target (e.g., the left target) as a second correct choice. So they relied on divergence, but varying angular deviation did not modulate divergence. Decreasing the number of targets (i.e., a 3-choice task, Experiment 2) with low and constant angular deviation did relax divergence, though target selection was not totally random. The dogs still chose as a first choice an inner target (i.e., the middle target) when selecting the most divergent patterns of elimination. Finally, in Experiment 3, the dogs were administered a 3-choice task with large constant angular deviation and in which all targets had been hidden. The dogs relied on divergence, choosing first an outer target (i.e., right or left) and the other outer target as the second correct choice. The results suggest that divergence is the outcome of a flexibility/cognitive load tradeoff when facing novelty and uncertainty.

To fulfill many daily activities (e.g., eating, mating) animals have to make decisions, which means that they must choose between alternative options (Bradbury & Vehrencamp, 2011). Such decisions, which can be crucial to the survival of animals, are often dependent one upon another. For example, one may have to visit many locations (Valsecchi, Bartolomucci, Aversano, & Visalberghi, 2000). In doing so, animals must remember the locations that have been visited and decide which one to choose next. A particular variant of this problem that has received much attention in the literature, both in humans and animals, is the traveling salesman problem. In this variant, all targeted locations should be visited before returning to the departure point. Given that such a journey requires time and energy searchers have asked to what extent animals make optimal choices. That is, can they use the most efficient route? Obviously, in this problem the distance between each location is a major determinant of efficiency. Empirical research revealed that in the long run animals perform better than chance but do not necessarily choose the most efficient route (Gibson, Wasserman, & Kamil, 2007; Howard & Fragaszy, 2014). According to Howard and Fragaszy (2014), whereas humans can plan their journey many steps ahead, animals probably rely on a one step ahead planning strategy based on the least distance rule (i.e., choose the nearest location).

In another variant of this problem, which has received much less attention, the traveler goes back to the starting point after each visit. In a typical task (i.e., the progressive elimination task), the animal is first trained to visit a single baited site before being introduced to the multisite set up. Then animals are let free to visit the sites in any order within the same trial as long as they deplete all sites. They are brought back to the starting point after each choice, whether the chosen site had already been visited or not. Under such

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circumstances, the issue of the most efficient route (in terms of traveled distance) is no longer relevant. This is so because, whatever the order in which animals visit the locations, the traveled distance will always be the same. One has just to sum up the round trip distance between each target and the starting point. In other words, the distance between each location is (theoretically) no longer a potent variable and there is no *a priori* reason to believe that animals will exhibit any preference regarding the order in which the locations are visited (as long as the distance between each target and the departure point is constant). In other words, random selection should be the default model. Randomness entails behavioral flexibility, which is a relevant strategy when facing uncertainty and/or novelty (see Dumas, 2000; Tervo et al., 2014). But randomness as a decision-making strategy also means ignoring potent incoming information (e.g., visible vs hidden targets, close vs far targets, number of targets) that could be used as a decisional criterion. Taking into account such informational cues (e.g., close vs far) would necessarily constraint (i.e., to implement a cognitive rule like the least distance rule) decision-making breaking down or restricting random selection as a decisional strategy; which raises the issue of the relationship between flexibility and cognitive load in decision-making (which will be referred to as the trade-off flexibility/cognitive load hypothesis).

Although some studies supported the default model both in dogs (Dumas & Dorais Pagé, 2006) and cats (Dorais Pagé & Dumas, 2003), empirical research revealed that most of the time animals like rats and even dogs and cats choose as the next location the farthest one (i.e., no random selection); that is they relied on what was referred to as the principle of maximum divergence (MD; see Lachman & Brown, 1957). Researchers suggested that MD should make it easier to visually discriminate between targets. However, neither the flexibility/cognitive load nor the discrimination hypothesis have been empirically tested so far (see below).

Lachman and Brown's study (1957) aimed at verifying whether rats could learn (i.e., to be errorless which required a large number of trials) a typical 4-choice progressive elimination task. After extensive training, rats did learn the task, exhibiting great variability regarding the order in which the locations were visited even when satisfying the learning criterion. The authors also reported that right from the outset rats chose as the next target the one that diverged the most from the previous choice; which they referred to as the principle of maximal divergence (MD). Lachman replicated these results using a 3- (1969) and 5-choice task (1965). According to Lachman and Brown, the typical stimulus-response approach could hardly account for the fact that rats did not develop stereotypy. They argued that rats should have rather relied on some sort of a cognitive map like what had been proposed by Tolman (1932). But more relevant to the present study, Lachman (1965) underlined that a divergent target is more easily discriminated and as such should be the next target to be visited.

Later Fabrigoule (1974) verified whether dogs could learn (i.e., to be errorless) an outdoor 4-choice task. Opposite to Lachman's studies, dogs were allowed to self-correct after a wrong choice instead of being brought back to the starting point. The results revealed that successful performance and MD were related. Fabrigoule argued, much in line with Lachman, that MD should help animals to discriminate between the targets, the larger the distance between two targets the easier it is to discriminate one from another; which can be referred to as the strict angular deviation version of the discrimination hypothesis. She also pointed out that, in order to solve the task, animals have to remember the already visited targets and that, the easier it is to discriminate between two targets, the easier it is to remember them; which suggests an interactive (i.e., memory × discrimination) version of the discrimination hypothesis. Fabrigoule did not disentangle between the two versions of her interpretation. Nonetheless, the memory × discrimination version certainly predicts less error than the strict angular deviation version. Poucet, Buhot-Averseng, and Thinus-Blanc (1983), using the same apparatus and procedure as those in Fabrigoule's study, observed MD in cats and they also suggested that MD could improve discrimination between the targets when solving the progressive elimination task.

Olton and Samuelson (1976), using an 8-arm radial maze to investigate spatial memory abilities, observed that rats often chose as the next target that one that was 90° apart, either on the right or the left, from the previous choice. In other words, rats appeared to rely on MD. In another study, Olton, Collison, and Werz (1977), using a 17-arm radial maze, observed that rats still spontaneously skipped arms to choose the next one like what was observed in Olton and Samuelson's study, but in a more systematic way; which suggests that divergence can be modulated (at least in frequency). Both versions of Fabrigoule's discrimination hypothesis can certainly account for such data.

In a more recent study, Dumas and Dorais Pagé (2006) reported two experiments in which dogs were administered a 3-choice progressive elimination task. Dogs were not allowed to self-correct after a wrong choice. Opposite to previous studies that required a very large number of trials to reach an errorless performance, in Dumas and Dorais Pagé's study dogs were administered a very limited number of trials. In other words, Dumas and Dorais Pagé focused on spontaneous behavior rather than on trained behavior. In Experiment 1, the distance between adjacent targets was constant like in Fabrigoule's study (1974). The results revealed that dogs visited the targets in a random order (i.e., the default model) contrary to what had been observed in Fabrigoule's study. Dumas and Dorais Pagé underlined that, although the distance between the adjacent targets was approximately the same in both studies, the distance between the starting point and the targets was larger in Fabrigoule's study than that in their study. Accordingly, angular deviation between adjacent targets was larger in their study (33°) than that one (17°) in Fabrigoule's study; which could account for the fact that dogs relied on MD in Fabrigoule's study but not in Experiment 1. These data can certainly be interpreted in terms of any of the two versions of Fabrigoule's discrimination hypothesis. But, one may argue that in Fabrigoule's study dogs relied on MD because they had to visit and remember 4 targets instead of 3. If that were the case, the strict angular deviation would not account for the data.

In Experiment 2 (Dumas & Dorais Pagé, 2006), the distance between adjacent targets varied so that there were two targets close to each other on one side of the bodily axis of the dog and only one target on the other side. Surprisingly, dogs spontaneously relied on divergence. Dumas and Dorais Pagé interpreted this result in terms of Gibson's hypothesis (1990) stating that information processing skills in social hunters (e.g., dogs) should differ from those of solitary hunters (cats). Cooperative hunters must pay attention both to conspecifics and the prey while hunting. Being too close to a conspecific would decrease hunting success. However Dumas and Dorais Pagé did not provide any proximal interpretation as to why dogs relied on divergence in Experiment 2 in their study. It could be that in Experiment 2 angular deviation between the close adjacent targets was small enough (i.e., 29°) per se (i.e., absolute judgment) to induce MD. This is quite unlikely as 29° is much closer to the 33° angular deviation used in Experiment 1 in Dumas and Dorais Pagé' study (2006) when dogs selected the targets in a random order than to the 17° angular deviation in Frabigoule's study (1974) in which dogs relied on MD. It is also possible that in Experiment 2 dogs relied on MD because they had to take into account two different angular deviations (29° vs 50°; i.e., relative judgment) within the same spatial array. Fabrigoule's discrimination hypothesis whatever the version can hardly account for these data.

In summary, empirical research revealed that animals relied on MD in a variety of settings in which either absolute (e.g., constant small angular deviation and/or large number of targets) or relative judgment (e.g., unequal angular deviation) was required. However, potent variables were often confounded, which leaves open the issue of the conditions eliciting MD. Second, whereas most of the studies insisted on assessing MD through extensive training, some studies (Dumas & Dorais Pagé, 2006; Lachman & Brown, 1957) revealed that animals spontaneously exhibit divergent behavior. It remains to be seen to what extent spontaneous divergence can be modulated. Third, from a theoretical point of view, Fabrigoule's hypothesis (1974) emphasizing MD as a way to improve target discrimination can hardly account for all the data. But the discrimination hypothesis has not yet been directly tested. Actually, the data suggest that animals rely on MD as cognitive information processing demands increase whatever the nature of stimuli (e.g., number of targets, small angular deviation, unequal angular deviation). A plausible alternative interpretation states that MD is the outcome of a flexibility/cognitive load trade-off. Then, MD should not allow better discrimination per se but rather maximization of flexibility when incoming relevant information (i.e., decisional criterion) compete with flexibility (i.e., random selection) in decision-making.

In brief, the present study aims at clarifying some of the conditions under which dogs spontaneously rely on MD in order to verify how divergence can be modulated. The study also aims at contrasting both versions of Fabrigoule's discrimination hypothesis and the flexibility/cognitive overload trade-off hypothesis as well.

Experiment 1

Experiment 1 had two goals. First, Experiment 1 aimed at verifying whether dogs could spontaneously rely on MD when having to process absolute informational cues (i.e., constant angular deviation); Fabrigoule's study (1974) not providing conclusive evidence on this point. In Fabrigoule's study, MD emerged as trials progressed, not spontaneously like in Lachman's studies. Fabrigoule did not address the issue of why divergence emerged late in her study. In Lachman's studies rats were brought back to the starting point after each choice whether it had already been visited or not. However, in Fabrigoule's study dogs were brought back only when they had visited a baited site; that is, dogs were allowed to immediately self-correct after a wrong choice. Then, dogs had to decide which target to visit next, but they were no longer facing equidistant targets from the new starting point. It is quite likely that, under such circumstances, they relied on the least distance rule (see Dumas & Dorais Pagé, 2006, Exp.1 condition 2; Dorais et al., 2003; Menzel, 1973), which would have delayed the emergence of MD. Accordingly, in Experiment 1 the dogs were administered a 4-choice progressive elimination task in which they were not allowed to self-correct after wrong choices.

Second, Experiment 1 aimed at testing both versions of Fabrigoule's discrimination hypothesis and the flexibility trade-off hypothesis as well. In order to do so, the dogs were administered four types of trials in which angular deviation remained constant or varied (i.e., mixed cues).

Method

Subjects

The subjects were nine (4 males and 5 females; 3 Labrador, 1 Spaniel, 1 Jack Russel, 1 Beagle, 2 Chihuahua, 1 unknown mixed bred) domestic pet dogs (*Canis familiaris*), which were tested in their owners' home. All dogs except one were experimentally naïve. The youngest subject was 1.5 year old and the oldest one was 12 years old (*M* = 5.4 years, *SD* = 3 years). Two more dogs were eliminated, one was sick and the other one did not cooperate.

Apparatus

Four identical plastic bowls (18 cm in height × 6.5 cm in diameter) and a large opaque panel (95 × 82 cm) were used. Also, pellets of dry commercial dog food were used.

Procedure

The experimental procedure was divided in two phases: training and testing. The owners were allowed to watch both training and testing. In order to prevent cueing, the owners were instructed to remain behind both the experimenters and the dog and to withhold from interacting (e.g., talking to the dog, gesturing towards the bowl, etc.) with the dog during the trials. Food was not available for at least 5 hours before training and testing sessions; water was available ad libitum.

Training. First, an experimenter (E1) gently restrained the animal by its collar at the starting point. While holding the dog's collar with one hand, E1 placed the large opaque panel in front of the dog. This procedure allowed another experimenter (E2) to set up the experimental apparatus (i.e., baiting and positioning the bowl) for the next trial without being viewed by the dog. This intertrial procedure was used throughout all training and experimental trials in the three experiments reported in the present study. Once the intertrial manipulations were completed, E2 returned behind E1 who then removed the panel and released the dog. The side (left or right) from which E2 came back behind the starting point and the side (left or right) from which E1 held the dog were counterbalanced across trials for each subject. There were 10 training trials within any training session and a single bowl containing a food pellet was used on each trial. On the first trial, the bowl was placed a few cm in front of the starting point. For the remaining nine trials, the position of the bowl was randomly chosen among 20 predetermined positions in a 2.2 x 1.6 m area located 20 cm in front of the starting point. None of these positions corresponded to any of the four target positions used in the experimental sessions. To succeed on any training trial the dog had to walk from the starting point to the bowl and to eat the food pellet within 30s, otherwise the trial was failed. Whether the dog succeeded or failed on any trial, E1 brought it back to the starting point, held its collar and placed the large opaque panel in front of it so that E2 could complete the intertrial manipulations. On each trial, E2 noted whether the dog had succeeded or not. Training was completed when the dogs could empty the bowl on 8 out of the 10 trials on two consecutive sessions. All dogs required only two sessions to satisfy this criterion.

Experimental trials. The experimental trials were administered on the session following the end of training. The large opaque panel was always placed in front of the dog between the trials allowing E2 to bait each of the 4 bowls and set up the experimental array (see below). Once E2 had completed the intertrial manipulations, E2 returned to the starting point and stood behind E1. Then E1 removed the large opaque hiding panel and released the dog. If the dog chose a baited bowl, it was allowed to eat the food pellet before being brought back to the starting point where it was released again. If the dog chose an already visited bowl, it was immediately brought back to the starting point by E1 where it was released again. On each trial E2 noted the order in which each bowl was visited and whether it was a first visit or a revisit (i.e., an error). A choice was defined as any behavior or head movement allowing visual access to the content of the bowl (i.e., bending the head in the bowl, leaning towards the inner part of the bowl, etc.). A trial was completed when all bowls had been emptied.

There were four types of trials. In each type of trial the distance between the starting point and the targets was constant but angular deviation between the adjacent targets varied. In Type 1 (absolute cues) trial, angular deviation between adjacent bowls was constant (i.e., 23°; see Figure 1). In Type 2 (mixed cues), angular deviation between each external bowl (e.g., left) and its adjacent inner bowl (e.g., inner left) was constant (i.e., 11.5°) but smaller than that between the two inner bowls (i.e., 46°). In Type 3 (mixed cues), angular deviation between the two right targets was 11.5°, 34. 5° between the two internal targets and 23° between the two left targets whereas in Type 4 trial it was the opposite.

Both versions of the discrimination hypothesis state that divergence is directly linked to angular deviation per se and predict that divergence will be higher in Type 2 trial (i.e., two 11.5° angular deviations) than in other types of trials. In addition, the strict angular deviation hypothesis predicts that Type 2 should produce more errors than other types of trials but not (tentatively) the memory × discrimination version of the discrimination hypothesis. According to the flexibility/cognitive load trade off hypothesis, Type 3 and Type 4 trial are associated with the highest cognitive load (i.e., one very low angular deviation and two different sets of unequal angular deviations between adjacent targets) so that divergence should be maximal in Type 3 and 4.

The dogs were administered nine trials for each type of trial. The order of presentation of the 36 trials was randomly determined for each dog. If the dog did not cooperate five times in a row or ran away in another room the session was ended. Four dogs needed two sessions to complete the experimental trials, five dogs needed three sessions.

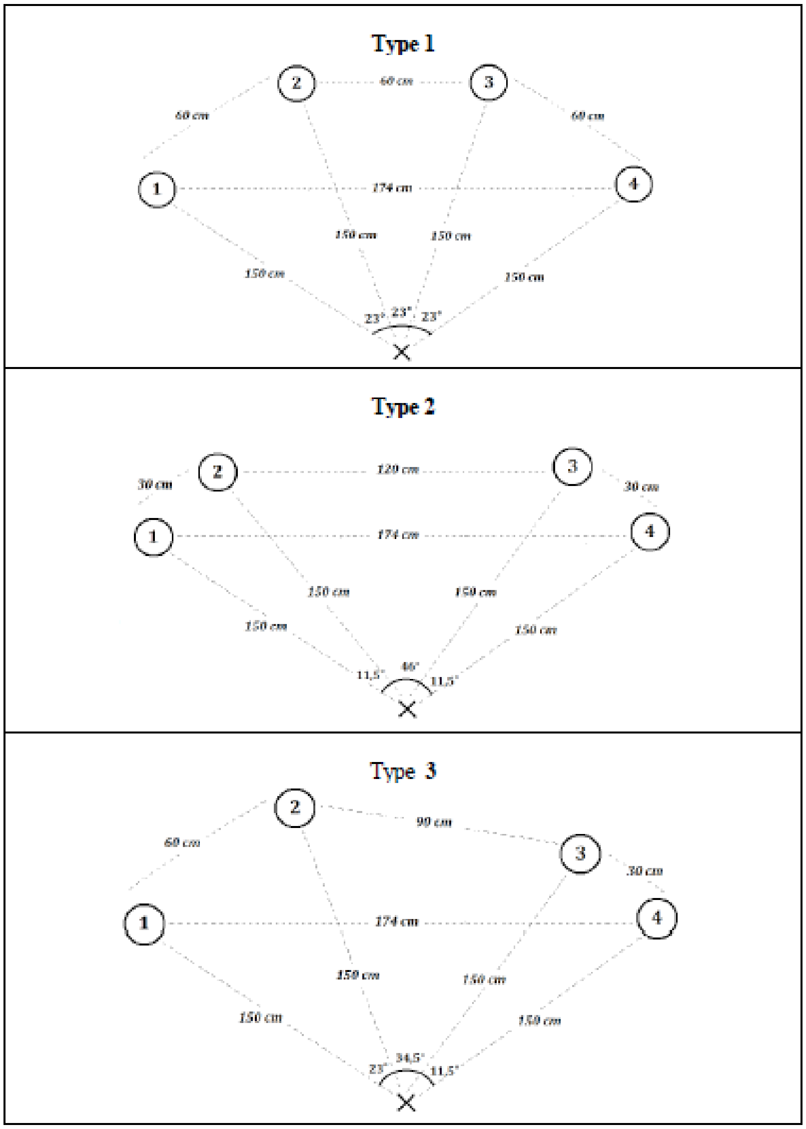

Figure 1. **A schematic representation of the spatial configuration of the baited bowls (1: external left, 2: internal left, 3: internal right, 4 external right) for each type of trial in Experiment 1.**

Results

The order in which the bowls were emptied (i.e., pattern of elimination) was noted on each trial for each subject. As there were four bowls in any trial, there were 24 possible patterns of elimination. In order to carry out statistical analyses raw data had to be regrouped and transformed.

First, each of the 24 possible patterns of elimination was attributed a divergence score (DS) based on angular deviation between successive correct choices on each trial. As there were four bowls, three angular deviations had to be summed up to yield any DS. For the sake of simplicity, angular deviations were converted into divergence units (see Table 1). For example, when the dogs emptied the bowls from left to right in Type 1 trial, angular deviation between successive correct choices was always 23° which is worth two units so that the DS was 6. Or, selecting first the left target, then the right one (i.e., 69° = 6 units), then the internal left (i.e., 46° = 4 units) and finally the internal right target (i.e., 23° = 2 units) yielded a 12 DS score. The lowest possible DS means that divergence was minimal, whereas the highest DS was associated with MD. Second, given that angular deviation between adjacent targets varied from one type of trial to another, the DS for one particular pattern of elimination could vary from one type of trial to another; which also means that each type of trial yielded a different number of DS values (see Table 2). Thus, in order to carry out between Type of trial comparisons, the DS values were regrouped in five levels (i.e., from Level 1 = minimal divergence to Level 5 = MD) for each type of trial. Central values were regrouped first and, if necessary, intermediate values (see Table 2). In doing so, for any level of divergence the number of patterns of elimination remained constant across the four types of trials (e.g., Level 1 always included the two lateral sweeping patterns whatever the type of trial) but varied within any type of trial (e.g., Level 1 included 2 patterns and Level 3 included 12 patterns). Third, in order to perform within Type of trial comparisons, the deviation between the number of times the patterns of elimination were chosen (i.e., the observed frequency) and the expected frequency (out of 9 trials) assuming random selection was computed for each level of divergence for each subject.

Table 1

Divergence units (DU) between correct successive choices as a function of angular deviation (°) and type of trial in Experiment 1

DU	1	2	3	4
1	-	11.5°	11.5°	11.5°
2	23°	23°	23°	23°
3	-	-	34.5°	34.5°
4	46°	46°	46°	46°
5	-	57.5°	57.5°	57.5°
6	69°	69°	69°	69°

Note. Maximum being always 69° between the far left and the far right target whatever the type of trial.

Table 2

DS values as a function of Level of divergence and Type of trial in Experiment 1

Type of trial	Level of divergence				
	1	2	3	4	5
1	6	8	10	12	14
2	6	7	8, 11, 14	15	16
3 & 4	6	7, 8	9, 10, 11, 12	13, 14	15
Number of patterns	2	4	12	4	2

A 4 (Type of trial) × 5 (Level of divergence) ANOVA with Type of trial and Level of divergence as repeated measures, computed on the number of times each pattern of elimination was chosen, revealed a significant Level of divergence effect, $F(4, 7) = 4.89$, $p < .01$, $\eta_p^2 = 0.37$. There was no significant Type of trial effect and no Type of trial × Level of divergence interaction. A *posteriori* comparisons (Newman Keuls, $p < 0.05$) revealed that the dogs chose significantly more often Level 5 than Level 1, 95% CI [.37, 1.68], Level 2, 95% CI [.62, 2.03], and Level 3, 95% CI [-.12, 1.96] patterns of elimination (see Table 3). *T*-tests also revealed that dogs exhibited Level 5 patterns of elimination significantly more often, $t(8)= 3.73$, $p = 0.006$, and Level 1 patterns and significantly less often, $t(8) = - 3.18$, $p = 0.013$, than what was expected assuming random selection. Further analysis in which the 36 experimental trials were divided in 3 blocks (e.g., block 1: trial 1-12 and so on) did not reveal any significant difference, $F(2, 16) = 1.51$, $p > 0.05$, regarding the mean number of times level 5 patterns of selection were chosen across the blocks of trials.

Table 3

Mean (M±SD) for both the number of times patterns of each level were chosen and error rate in Experiment 1

	Frequency*		Error rate	
Level	M	SD	M	SD
1	-.250	(±.37)	1.60	(±1.48)
2	-.556	(±.45)	2.43	(±0.81)
3	-.139	(±.77)	1.92	(±0.53)
4	.194	(±.62)	1.99	(±0.75)
5	.750	(±.71)	2.10	(±1.05)

Note. * Expected frequency assuming random selection was subtracted from raw score.

Errors were also analyzed. First, a 4 (Type of trial) × 4 (Position of the target) with repeated measures on these two factors computed on the number of errors did not reveal any significant effect. Second, as researchers had suggested that MD should facilitate discrimination between targets, one would expect, within any condition, Level 5 patterns of elimination to be associated with a lower rate of errors than the patterns of any other level, or at least than those of Level 1 and Level 2. Tentatively, the flexibility/cognitive load hypothesis makes the same prediction but for a different reason. Assuming that MD is the outcome of a competition between informational cues and the default model, minimal divergence would mean unsolved competition and be associated with an increased rate of errors. So, for each subject an error rate was computed for each level of divergence (see Table 3). An ANOVA with Level of divergence (5) as a within subject variable did not reveal any significant effect, $F(4, 32) = 1.01$, $p > 0.05$.

Discussion

First, the results of Experiment 1 revealed that the dogs spontaneously relied on MD when absolute cues were available (i.e., Type 1 trial). This result can account for the fact that in Fabrigoule's study (1974) MD emerged late because of a competition between MD and the least distance rule in decision making. In Fabrigoule's study the dogs could self correct wrong choices but not in Experiment 1.

Second, the results revealed that the dogs did not rely more or less often on divergence whether absolute or mixed cues were available. That is, mixed cues did not modulate divergence. These results do not support the strict angular deviation version hypothesis, which predicted higher divergence and more errors in Type 2 trial than in other types of trial. But it could be that in all types of trial there was at least one low angular deviation, whether it was 11.5° or 23°, which was sufficient to induce MD. Hence, the strict discrimination hypothesis needs to be further tested. The data also failed to support the memory × discrimination hypothesis regarding divergence. One may argue that, although angular deviation between adjacent targets varied within each type of trial, the overall angular deviation (i.e., 69°) to be assessed was constant across types of trial. The flexibility/cognitive load hypothesis predicted that divergence should be highest in Type 3 and Type 4 trial. Again, the data do not support this prediction. It is possible that the dogs took into account all types of cues regarding angular deviation and that, beyond a particular level of cognitive load, any further relevant information was ignored; which would account for the fact that mixed cues did not modulate MD.

Finally, all three hypotheses predicted, but for different reasons, that error rate should drop from Level 1 (i.e., minimal divergence) of divergence to Level 5 (i.e., maximal divergence). Surprisingly, that was not the case (see General Discussion on this point).

Experiment 2

In Experiment 1 the dogs relied on MD when they were administered a 4-choice task with a small angular deviation (e.g., Type 1 trial). However, previous data (Dumas & Dorais Pagé, 2006) revealed that dogs randomly selected the targets when being administered a 3-choice progressive elimination task with a large angular deviation. Experiment 2 aimed at verifying whether decreasing the number of targets but still having a small angular deviation would relax MD. Given that memory load will be lower in Experiment 2 than it was in Experiment 1, both the flexibility trade-off hypothesis and (tentatively) the memory × discrimination hypothesis predict that MD will be relaxed. On the opposite, the strict angular deviation hypothesis predicts that the dogs will still rely on MD because at least one small angular deviation appears to be sufficient to induce divergence (see Experiment 1).

Method

Subjects & Procedure

The subjects were eight (3 males and 5 females; 2 Labrador, 1 Lhasa Apso, 1 Jack Russell, 1 Airedale Terrier, 1 Boston Terrier, 1 Bernese Mountain, 1 Maltese) domestic pet dogs (*Canis familiaris*), which were tested in their owners' home. Two dogs had participated in Experiment 1 a year before while the remaining six dogs were experimentally naïve. The youngest subject was 1 year old and the oldest subject was 12 years old (*M* = 3.9 years, *SD* = 3.6 years).

The dogs were trained and tested following the same procedure and criterion as in Experiment 1. All dogs needed only two sessions to satisfy the training criterion. They were administered a 3-choice task (one target being in line with the body axis of the dog, one on the left and one on the right) in which angular deviation between adjacent targets was constant and identical to that one used in Type 1 trial in Experiment 1 (i.e., 23°). We referred to Dumas and Dorais Pagé's study (Condition 1, Exp1, 2006) regarding data supporting the default model and in that study the distance between the starting point and the targets was slightly larger (i.e., 2 m) than that in Experiment 1 (i.e., 1.5 m). So, in order to control for absolute distance the subjects were equally divided in two groups. In Group 1 the distance between the starting point and the bowls was 2 m like in Dumas and Dorais Pagé's study and the distance between adjacent targets was 80 cm whereas in Group 2 the distance between the starting point and the bowls was 1.5 m like in Experiment 1 and the distance between the adjacent targets was 60 cm (see Figure 2). Angular deviation was the same (i.e., 23°) in both groups. Each subject received 10 experimental trials. Seven dogs needed 1 session to complete the experimental trials and one dog needed 2 sessions.

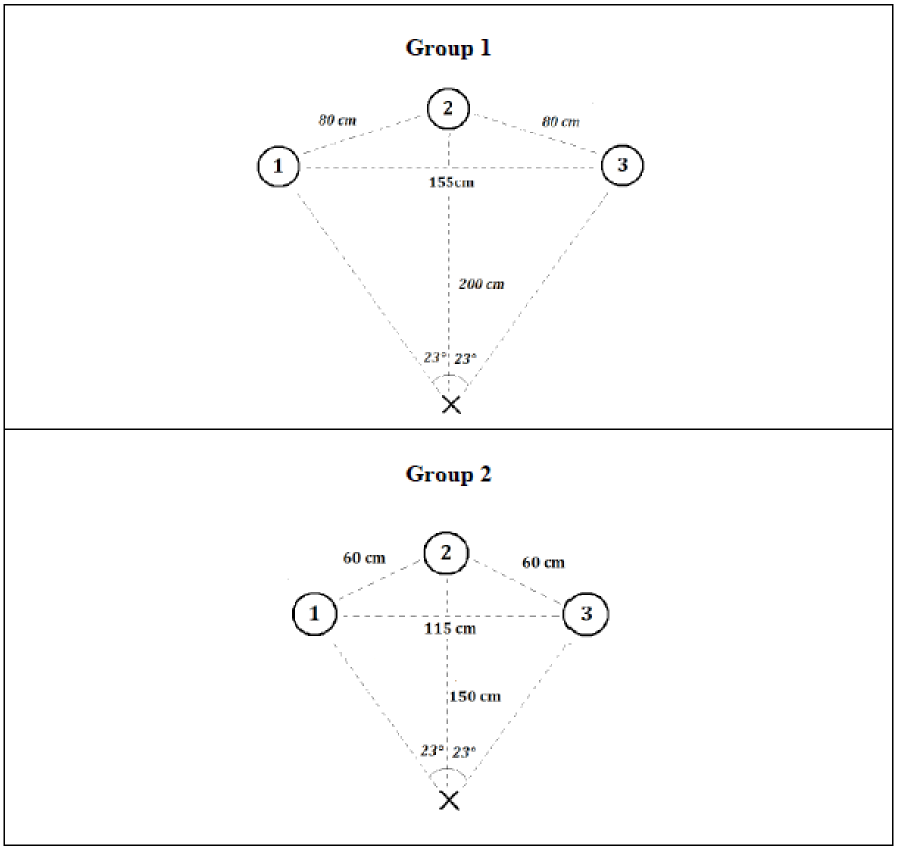

Figure 2. **A schematic representation of the spatial configuration of the baited bowls (1: left 2: intermediate, 3: right) for each group in Experiment 2.**

Results

Given that there were three bowls, there were only six possible patterns of elimination and two divergence levels. Level 1 (i.e., minimal divergence) included the two lateral sweeping patterns and Level 2 the four other patterns, which yielded exactly the same DS. Finally, for each subject the frequency with which the pattern of elimination were chosen within any level of divergence was subtracted from the expected frequency assuming random selection.

A 2 (Group) × 2 (Level of divergence) ANOVA with repeated measures on Level of divergence, did not reveal any significant difference. Nonetheless, as Level 2 divergence included two types of patterns of elimination, those patterns in which the dogs emptied first an external bowl (e.g., right-left-intermediate) and those in which they emptied first the intermediate bowl (e.g., intermediate-right-left), these two types of pattern of elimination were compared. The analysis computed on raw scores revealed that the dogs emptied first significantly, *t*(7) = 2.75, *p* = 0.029, *d* = .97, more often the intermediate bowl (*M* = 4.75, *SD* = 0.93) than an external bowl (*M* = 2.50, *SD* = 2.05); 95% CI [.35, 4.15].

A 3 (Position of the bowl) × 2 (Group) ANOVA on the mean number of errors revealed no Position effect, *F*(2, 12) = 0.79, *p* > 0.05, no Group effect, *F*(1, 6) = 3.98, *p* > 0.05 and no significant interaction, *F*(2, 12) = 0.68, *p* > 0.05. Finally, a comparison of error rate among the three types of patterns of elimination (i.e., Level 1, Level 2 internal and Level 2 external) did not reveal any significant difference (see Table 4).

Table 4

Mean error rate (M ±SD) for each level of divergence in Experiment 2 and 3

	Exp. 2		Exp. 3	
Level	M	SD	M	SD
1	1.08	(±0.77)	1.74	(±1.31)
2 int	0.81	(±0.66)	1.19	(±0.83)
2 ext	1.55	(±1.33)	1.46	(±0.64)

Note. int: search initiated at the intermediate location; ext = search initiated at an external location.

Discussion

The results of Experiment 2 revealed that the dogs did randomly select between maximal divergent (i.e., Level 2) and minimal divergent (i.e., Level 1) patterns of elimination. Hence, decreasing the number of targets did relax MD. However, pattern selection was not totally random contrary to what had been observed in Dumas and Dorais Pagé’s study (2006). When selecting the most divergent patterns (i.e., Level 2) the dogs systematically initiated search at the intermediate target. The fact that angular deviation was smaller in Experiment 2 than that in Dumas and Dorais Pagé’s study can certainly account for such a discrepancy. This suggests that the number of targets is a potent variable but that angular deviation also influences the way animals select the targets. Overall, these results support both the interactive version of the discrimination hypothesis and the flexibility trade-off hypothesis, but definitely not the strict angular deviation version.

Experiment 3

Experiment 3 aimed at contrasting the discrimination hypothesis and the flexibility trade-off hypothesis. So far, empirical research on MD focused on the impact of angular deviation and the number of targets. As such, the discrimination hypothesis is clearly tied to metric information (see Gallistel, 1990). A way to contrast the discrimination hypothesis and the flexibility/cognitive overload hypothesis would be to administer a progressive elimination task in which decision-making depends upon nonmetric informational cues. Previous work revealed that, although mammals possess object permanence allowing them to recover hidden objects, having to solve a task in which the targets are hidden increases cognitive load. For instance, Dumas, St-Louis, and Routhier (2006) showed that, when there was a conflict between the representation of a previously visible but now hidden target and the representation of a hidden object whose hiding screen was no longer visible, the former overrode the latter. Hence, Experiment 3 aimed at verifying whether dogs will rely on MD when having to search for hidden targets using the same spatial array (i.e., 3-choice task with large angular deviation) in which they had randomly selected visible targets (Dumas et al., 2006). Whereas the interactive version of the discrimination hypothesis predicts that dogs should randomly select the targets, the flexibility trade-off hypothesis predicts that they will rely on MD.

Method

Subjects

The subjects were eight (3 males and 5 females; 2 Labrador, 1 Rottweiler, 1 Jack Russell, 1 Husky, 1 Bernese Mountain, 1 Shih Tzu, 1 unknown mixed bred) domestic pet dogs (*Canis familiaris*), which were tested in their owners' home. All dogs were experimentally naïve. The youngest subject was 9 months old and the oldest subject was 9 years old (*M* = 3.8 years, *SD* = 2.9 years).

Apparatus

Three identical plastic bowls (18 cm in height × 6.5 cm in diameter), three hiding wooden screens (20 x 30 cm) and the large opaque panel (95 × 82 cm) were used. Also, pellets of dry commercial dog food were used.

Procedure

Training. Like in Experiment 1 and 2, E2 baited and positioned the bowl for the next trial during the intertrial interval (i.e., when the large opaque panel was in front of the dog); in addition E2 placed a hiding screen just behind the bowl in order to familiarize the animal with its presence. Thereafter the large opaque panel was removed and the dog was released. There were 20 training trials. On the first training trial the bowl was close to the starting point like in the first two experiments. For the next four trials the distance between the bowl and the starting point was gradually increased up to 2 m. On these first five trials the bowl was always visible. For the last 15 trials the target was placed on one position randomly chosen among 15 predetermined positions in a 2.2 × 1.6 m area located 20 cm in front of the starting point. None of these positions corresponded to any of the three target positions used in the experimental session. In addition, to make sure that each subject had object permanence, on some of these last 15 training trials the dogs had to reach for a hidden target. However, given that Dumas et al. (2006) showed that relying on a representation of a hidden object increases cognitive load per se, to exploratory purpose we wanted to verify whether systematically relying on such a representation during training would decrease cognitive load during the experimental trials. Hence, for half of the subjects, the target was hidden behind the hiding screen on 5 trials randomly selected among these last 15 training, whereas for the other half the target was hidden on all last 15 training trials. For all trials on which the object was hidden, once the opaque panel had been removed, E2 stayed behind the target. When the animal was attentive (i.e., looking at the target), E2 moved the target behind the hiding panel before coming back behind E1, after which the dog was released. Training was completed when the dogs could empty the bowl on 17 out of the 20 trials. All subjects needed only one session to complete training.

Experimental trials. The experimental trials were administered in the session following the end of training. On each experimental trial there were three bowls and three hiding screens. The spatial array was exactly the same than that used by Dumas and Dorais Pagé (2006) in which dogs randomly selected the visible targets, that is there were three bowls and angular deviation was constant (33°) between adjacent targets. In addition hiding screens were present (see Figure 3). The experimental procedure was the same than that in the first two experiments except that on each trial, once the large opaque panel had been removed, E2 moved each bowl behind its hiding screen.The order (1st, 2nd, 3rd) in which the bowls (i.e., left, intermediate and right) were manipulated (i.e., moved behind the opaque screen) was counterbalanced across the trials for each subject. Once this manipulation was completed E2 came back behind E1 and the dog was released.

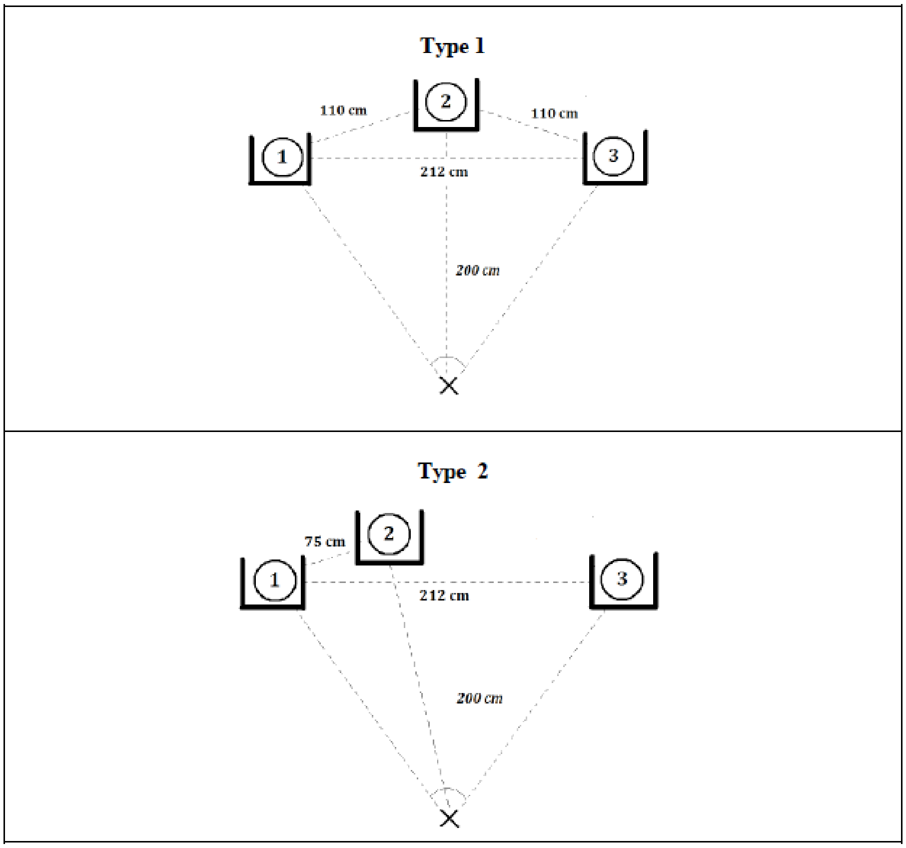

Figure 3. **A schematic representation of the spatial configuration of the baited bowls (1: left 2: intermediate, 3: right) for each type of trial in Experiment 3**.

There were three types of trial. In Type 1 trial the angular deviation between the adjacent targets was constant like in Dumas and Dorais Pagé's study (Exp 1, 2006) but a bit smaller (i.e., 30° instead of 33°) given that the hiding screens are a bit larger than the target bowls. In Type 2 and Type 3 trial, the intermediate target was placed close to one of the two external bowls instead of being in line with the bodily axis of the dog. In Type 2 trial, angular deviation between adjacent targets were respectively 19° (left-intermediate) and 41° (intermediate-right), in Type 3 trial it was the opposite. Each subject was administered eight trials of each type. The order in which the 24 experimental trials were administered was randomly determined for each subject. Seven subjects completed the experimental trials in two sessions and one subject needed only one session.

Results

As there were three bowls there were six patterns of elimination and two divergence levels. In Type 1 trial angular deviation was constant. Accordingly, Level 1 included the two lateral sweeping patterns of elimination (e.g., from left to right) and Level 2 included the four other patterns. In Type 2 and Type 3 trial angular deviation differed between adjacent targets and Level 1 also included the two lateral sweeping patterns. However, the two patterns in which the two close targets were correct successive choices yielded a lower DS than the two patterns in which the intermediate and the far external targets were correct successive choices. A preliminary 2 (Type of trial, i.e., Type 2 vs Type 3) × 2 (DS) ANOVA with repeated measures on both factors did not reveal any significant effect. Thus, for both Type 2 and Type 3 trials the four patterns of elimination were pooled within Level 2.

Then a 3 (Type of trial) × 2 (Training) × 2 (Level of divergence) ANOVAwith repeated measures on Type of trial and Level of divergence did reveal only a significant Level of divergence effect, $F(1, 7) = 7.43$, $p < 0.04$, $\eta_p^2 = .55$. The dogs significantly chose more often Level 2 patterns of elimination ($M = 0.92$, $SD = 1.04$) than Level 1 patterns ($M = -0.92$, $SD = 1.04$), 95% CI [17, 3.67].

Like in Experiment 2, we compared the internal variant and the external variant of Level 2 pattern of elimination. So for Level 2 patterns only, a 3 (Type of trial) × 2 (First choice, intermediate vs external; i.e., internal vs external) ANOVA with repeated measures on both factors, revealed only a significant First choice effect, $F(1, 7) = 8.35$, $p = 0.02$, $\eta_p^2 = .54$. The dogs initiated searched more often at an external bowl ($M = 4.92$, $SD = 1.30$) than at the intermediate target ($M = 2.00$, $SD = 1.17$); 95% CI [.41, 4.16]. There was no difference between the left and the right bowl as a first choice.

A 3 (Position of the bowl) × 3 (Type of trial) ANOVA on the mean number of errors did reveal only a significant Position x Type of trial interaction, $F(4, 28) = 5.00$, $p < 0.01$. Further analyses revealed that the number of errors differed among the three positions only in Type 2 trial, $F(2, 14) = 9.56$, $p = 0.002$, $\eta_p^2 = .57$. A posteriori Bonferoni comparisons revealed that the dogs erred less often at the intermediate target ($M = 2.13$, $SD = 1.81$) than at the left target ($M = 5.88$, $SD = 2.17$); 95% CI [1.41, 6.09].

Finally, a 3 (Type of pattern of elimination; i.e., Level 1 pattern, internal Level 2 pattern and external Level 2 pattern) one-way Anova computed on the rate of error did not reveal any significant difference (see Table 4).

Discussion

Experiment 3 aimed at contrasting the discrimination and the cognitive overload hypotheses. The results supported the cognitive overload hypothesis. The dogs relied on MD when all targets were hidden. They also initiated search at an external location. Extensive training with hidden objects during training did not decrease cognitive load in experimental trials objects. Nonetheless, further research should address this issue.

General Discussion

The goal of the present study was twofold. First, the study aimed at clarifying some of the conditions under which dogs spontaneously rely on MD in order to verify how divergence can be modulated. Second, the study also aimed at contrasting both versions of Fabrigoule's discrimination hypothesis and the flexibility/cognitive overload trade-off hypothesis as well. The results revealed that spontaneous divergence is a robust phenomenon in dogs. Informational cues such as the width of angular deviation, the number of targets and the visibility of the targets as well induced spontaneous divergence. The data clearly supported the flexibility/cognitive load hypothesis.

One of the main finding of the present study was the fact that, when decision-making was constrained (e.g., low angular deviation, high number of targets, hiding the targets) the dogs modified their first choice. In the 3-choice task with low angular deviation (i.e., Exp. 2) the dogs did not rely on MD, but target selection was not totally random. They initiated search at the intermediate target when selecting the most divergent patterns of elimination. The dogs also selected first an internal target (i.e., the left or the right internal target) in the 4-choice task (see Lachman & Brown, 1957 for a similar phenomenon). Choosing an internal target first is certainly a relevant strategy as it keeps flexibility high. Under such circumstances, the targets adjacent to the chosen one remain available options whereas selecting an external target first would necessarily leave only one target as an available option. As already underlined, behavioral flexibility is relevant when facing novelty and or uncertainty. In the present study, the dogs were trained to reach a single baited bowl. When being administered the experimental trials they were facing three or four bowls for the first time (e.g., novelty) and they did not know which one was baited or whether all bowls were baited (i.e., uncertainty).

When the dogs were administered a 3-choice task in which all targets were hidden, they relied on MD and they chose an external target as a first choice. First, this suggests that hiding the targets per se increases cognitive load more than increasing the number of targets and/or decreasing angular deviation. Second, the trade-off hypothesis predicts that as cognitive load increases, it will be more difficult to implement the default model (i.e., random selection) so that flexibility should be reduced. One strategy under high cognitive load consists in cutting down options (i.e., reducing flexibility). Selecting an external target first necessarily limits the options; only one option remains available. It remains to be seen whether dogs would also select first an external target in 4-choice task in which all targets are hidden.

But one may argue that, when all targets were hidden, selecting an external target first supports the discrimination hypothesis. One should expect visual discrimination to be taxed with low but not with large angular deviation like that one used in Experiment 3. It is also unlikely that visual discrimination was taxed given that even the smallest angular deviation used in the present study was far above the threshold value necessary to discriminate alternate visual patterns in this species (Miller & Murphy, 1995). One likely explanation states that decreasing angular deviation, which also means decreasing the distance between two adjacent targets, increased the probability of being an option according to the least distance rule. In other words, small angular deviation (at least like that one used in the present study) does not mean taxing visual discrimination as previous research assumed, but rather increasing the probability of being part of the same cluster.

So, constraining decision-making influenced which target was chosen first. Previous research defined divergence in terms of the distance between the “next choice” and the previous one. It was implicitly assumed that the variables eliciting MD or divergence should not affect the first choice per se but rather which target will be chosen next. Our data did not support this assumption.

The data revealed that constraints on decision making also influenced the “next choice” as assumed in the literature. Admittedly, the 3-choice task can hardly be of heuristic value regarding this particular issue, especially when the intermediate target is selected first because the second correct choice (i.e., either the left or the right target) is a forced choice. But in both the 3-choice task with hidden targets and the 4-choice task, the dogs skipped the target adjacent to the first selection when selecting the second correct choice. Again, this strategy keeps flexibility high. It reduces the probability of searching back at the previous chosen (i.e., already assessed) location.

In some way, it is not so surprising that in previous research rodents, canids and felids did not readily rely on lateral sweeping (e.g., from left to right) to master the progressive elimination task even after extensive training, although it looks like as the most efficient strategy from a memory point of view. Not only spontaneous lateral sweeping entails stereotypy that would be detrimental to flexibility, but it also requires a multistep ahead planning strategy, which animals do not exhibit (Howard et al., 2014). Actually, after extensive training these species relied on MD. But rather than always relying on the same pattern of elimination they varied their selection among the most divergent patterns. It remains to be seen whether spontaneous divergence differ or not across species.

Overall the data support the flexibility trade-off hypothesis. However, it remains to be explained why MD did not influence the rate of errors. Admittedly previous research (Fabrigoule, 1974; Poucet et al., 1983) showed that, on the long run, errorless performance in the progressive elimination task was clearly associated with MD. This is not the case regarding spontaneous MD. Chittka, Skorupski, and Raine (2009) argued that quite often decision-making entails a speed/accuracy trade off. That is, under some circumstances (e.g., foraging in a novel environment), accuracy may suffer given that it could be more important to allow cognitive resources to environmental sampling for example. This clearly suggests that there is also a flexibility/accuracy trade-off. MD or divergence is a spontaneous behavior (see below). As such it is crucial to the survival of animals and it requires quick decisions as what to do and not to do. However, it remains to be verified to what extent more complex or more costly setting would still favour flexibility over accuracy. Further research is needed to clarify this point.

The flexibility/cognitive load hypothesis states that beyond a certain level animals may ignore relevant informational cues as decisional criteria. For instance, when they were administered the 4-choice task (i.e.,Exp. 1), the dogs behave the same way whether absolute or mixed cues were available. In addition, some data suggest that animals can even totally discount incoming relevant information and fall back on the default model as a decisional strategy. Both dogs (LeBlanc & Dumas, 2007) and cats (Dorais Pagé & Dumas, 2009) were administered a 3-choice task in which they had to visit either one visible (i.e., the distinct target) and two hidden targets (i.e., the two equivalent targets) or the opposite (i.e., one hidden and two visible targets). When the distinct target was on the intermediate location, animals chose the visible target(s) first. That is, they implemented the visibility rule. However, when the distinct target was on the right location they randomly (i.e., default model) selected the targets. As such they ignored visibility as a decisional criterion. The nature of the mechanism underlying this phenomenon still remains to be clarified. Nonetheless, such flexibility in decision-making allows animals to keep going on searching rather than giving up (see also Tervo et al., 2014).

MD refers to the fact that animals choose as the next target the farthest one. Basically divergence entails switching from one target to the other, which researchers (Lachman, 1969; Olton, 1976; Poucet et al., 1983) have referred to as spontaneous alternation (SA). Typically SA has been investigated with a 2-choice forced task whereas MD has been studied with the multi-choice task. In both cases switching is spontaneous but in the typical SA task there is usually no way to assess divergence. In the literature much more attention has been devoted to SA than to MD. SA has been interpreted in terms of foraging and exploratory behavior (see Richman, Dembe,r & Kim, 1986). As a foraging strategy switching has been referred to as the win shift strategy, which characterizes species depending upon food resources whose distribution and replenishing vary in space and time. Dogs are canids and as such depend upon mobile preys. In addition recent data (MacPherson & Roberts, 2010) revealed that dogs learn more easily a win shift task than a win stay task. SA has also been interpreted as exploratory behavior. Switching from one target to the other should certainly be of adaptive value especially when invading new environments (for a recent case see Ramey, Teichman, Oleksiak, & Balci study on the green crab, 2009).

Lachman and Brown (1957) coined the term principle of maximal divergence to account for the fact that in a progressive elimination task rats chose as the next choice the farthest target. Then, divergence was conceptualized as a way to improve performance under restricted discriminative conditions. Our study rather suggests that divergence appears to be a way to maximize flexibility in decision making when taking into account online relevant information that otherwise should be ignored as decisional criterion and that selecting the first target is as relevant as selecting the next one.

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