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Article 1

Semantic Priming and Stimulus Equivalence

Article 2

Effect of Pre-Training with Rapid Responding on Formation of Equivalence Classes

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Semantic Priming and Stimulus Equivalence

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Abstract

Semantic priming and stimulus equivalence are research areas that study relations between stimuli. Semantic priming researchers are interested in the reaction time between a prime and a following target. The differences in reaction time are used to make inferences about how we store and retrieve knowledge. Stimulus equivalence researchers present their participants with conditional discrimination training with seemingly meaningless stimuli. After this training it is possible to present a test for derived relations and the participants will respond correct to stimuli that never has been presented together. The purpose of this paper is first to give an introduction to semantic priming, and procedures used in semantic priming research. Secondly to present stimulus equivalence, and procedures from stimulus equivalence research. The discussion will focus on how procedures from semantic priming can be used in stimulus equivalence research. There will also be suggestions for further research in stimulus equivalence based on results from unconscious priming.

Keywords: stimulus equivalence, semantic priming, behavior analysis, short latencies, limited hold

Semantic Priming and Stimulus Equivalence

By presenting someone with the word BREAD, there is a high probability that they will respond quicker to the word TOAST, than to the word RADIO. The same goes for the word BREAD and BUTTER. How do we do this? What behavior could account for these results? The examples come from studies of semantic priming and associative priming. These are word-word relations and are studied in adults. But what about word-object and object-word relations and children? Very young children are able to derive relations between objects and words with very little training, and the number of relations has an exponential growth. What is the best way to study this phenomenon? What behavior could account for these results? Behavior analysis has been criticized for being too simple to be able to account for how language is learned. Research in stimulus equivalence study the emergence of derived relations has given and will continue to give important insight to how language is learned. Both semantic priming and stimulus equivalence study relations between symbolic stimuli (words or symbols), but they do this from a very different perspective.

The purpose of this paper is twofold. The first is to give a presentation of the two research areas with a focus on a selection of procedures. And second by comparing similarities from these two areas to present arguments for new research. A suggestion for a study of stimulus equivalence and short latencies with the use of some procedures from the study of unconscious semantic priming will be made.

Semantic priming

Humans possess a lot of knowledge about the world. One research area within cognitive psychology is how this knowledge is stored. Since this “storage” is not easily accessible, they are studying behavior that could give clues to how humans store their knowledge. More broadly semantic is the study of meaning (Best, 1995). This knowledge is stored as words, symbols and relations between words and symbols in semantic memory. Memory of events and personal experiences and the relations among these are stored in episodic memory (McKoon & Ratcliff, 1979). A mental thesaurus or lexicon is used as an analogy for semantic memory (Best, 1995; McKoon & Ratcliff, 1979). According to Best (1995) there are three findings that cognitive researchers agree on when it comes to lexical access, or the study of words in the lexicon. These three are; frequency of use makes the word more available, infrequent words are as available as frequent words after repetitive priming and last that the availability can be manipulated by the presentation of words that are semantically related. Availability translates to the systematical variations in reaction time. Semantic priming is the study of how reaction time varies as a function of how this knowledge is stored and activated (Best, 1995).

Semantic priming is a name for the phenomena in which the showing of a word, picture (McNamara, 2012) or auditory stimulus (Gulan & Valerjev, 2010) can improve the probability of the response to a second word. We can observe this phenomenon by measuring reaction time to the second word. The closer they are related, the shorter the reaction time (Donahoe & Palmer, 2004; Neely, 1991; Palmer, 2009). In both Neely (1991) and McNamara (2012) semantic priming is used as an umbrella term for different types of priming, such as semantic, associative, mediating and episodic. If there is a relationship between the two words, the response to the second word will be faster than if the words are unrelated.

Palmer (2009) use BREAD and BUTTER as an example. Since BREAD and BUTTER are members of the class ‘what you eat for breakfast’ the presentation of one of them is said to prime the other. The metaphor of a bottle with bubbles is used to explain this when it comes to responses and how likely they are to occur at any given moment. The same picture can be used to represent possible stimuli. When BREAD is presented, the bubbles representing words in the classes ‘what you eat for breakfast’, ‘food’ and ‘things you buy at the bakery’ rises. While the bubbles that represent words in other classes as ‘vehicles’, ‘instruments’ or ‘clothing’ sinks. BREAD and BUTTER have an associative relation while BREAD and TOAST have a semantic relation.

The studies of semantic priming started with a study by Meyer and Schvaneveldt (1971). McNamara (2012, p. 3) claims that: “this article would become one of the most influential articles published in cognitive psychology”. Neely (1991) also acknowledged the importance of their article. The two reviews of semantic priming by Neely (1991) and McNamara (2012) provides the basis for this overview of semantic priming, and where it is possible the original articles have been cited. Neely (1991) focuses primarily on single-word presentation and presents finding from both lexicon decision tasks and pronunciation tasks. He excludes studies of repetition priming from the review. McNamara (2012) continues the review of the field of semantic priming since Neely’s review from 1991.

The next section presents a selection of parameters from semantic priming procedures and the processes automatic, strategic and unconscious priming.

Semantic priming procedures and processes

This is an overview of some selected parameters from semantic priming experiments.. The following parameters have been selected: single-word and two-word presentation, responding by keypress or pronunciation, what kind of stimuli is used, lexical decision task, stimulus onset asynchrony, interposing unrelated word (also called lag), repeated presentation of prime, response to prime, baseline measurement and from unconscious priming: threshold setting procedure, response-window and adjusting of the response-window.

Procedures in semantic priming research have these main elements; presentation of the stimuli, how the participant responds, selection of stimuli and different temporal variations. The stimuli in semantic priming studies are called *prime* and *target*. Prime is the first word and target is the word that the participant responds to.

There are two ways to present the stimuli. The target can be presented alone or together with the prime. The first one is called a single-word presentation (Neely, 1991) and here the target is presented alone. In the two-word presentation the prime and the target are visible at the same time and the participant responds based on both words. The participant will press a key for SAME and another key for DIFFERENT according to four different scenarios: two words, two non-words, prime as word and target as non-word or prime as non-word and target as word. Two-word presentation was used by Meyer and Schvaneveldt (1971) and was according to (Neely, 1991) mostly used in the earlier years of semantic priming. Two-word or compound presentation is used mostly to study backward priming and here the participants respond to both words. In single-word presentation participants are instructed to press YES or NO, or “Press YES if the word is an actual word”. (McNamara, 2012). This decision, whether the last word is a word or not seems to be the basis of the semantic priming paradigm.

The response can be either a selection with keystroke, button or touch screen or a pronunciation of the target word. Reaction time to target word or word compound is the dependent variable and participants are instructed to respond as quickly as possible to a task presented by the experimenter. Usually the task is to identify whether the target word is an actual word. In compound tasks, the response is sometimes related to whether both words are actual words. This is called a lexical decision task (LDT). Pronunciation responses are simply to pronounce or name the word if it is an actual word. To make pronunciation of non-words possible, they are made pronounceable. The pronunciation of a non-word is counted as an error. According to McNamara (2012) the pronunciation or naming are sometimes referred to as a "gold standard" in the study of semantic priming. He does not share this view and treats lexical decision tasks and pronunciation tasks equally (McNamara, 2012).

The stimuli used in semantic priming studies are words, non-words or so called neutral stimuli which can be the words "blank" or "neutral", or a string with a number of similar letters (XXXXX) or pronounceable non-words (McNamara, 2012). The words can be more or less related (Neely, 1991). The selection of words in semantic priming studies comes from lists that have investigated the semantic and associated relation between words Postman and Keppel (as cited in Gulan & Valerjev, 2010, p. 54) is such a list. Another example is Battig and Montague (1969) which presents norms for words in 56 different categories. According to (McNamara, 2012) the definition of how to treat relatedness has changed from rather strict to a more loose definition. A pure semantic relation would be cow and dolphin which both are mammals, but there will rarely be an associative relation between cow and dolphin (Gulan & Valerjev, 2010). An associative prime for cow could for instance be milk. When words are used to study semantic priming it is of importance how often the words are presented to avoid effects of repetition priming (McNamara, 2012). This problem is solved by counterbalancing the lists of words so that one participant sees a word as an unrelated or related prime while another participant sees the same word as a target with the opposite relation (McNamara, 2012).

Repetition priming is a procedure where the prime is presented more than one time (Neely, 1991). The repetition of the prime will increase the prime effect. Sometimes repetition is studied with *lag* or interfering stimuli. Lag can be used in at least two ways according to McNamara (2012). One way is to present the prime and lag like this: prime – lag – repeated prime – lag – target. This is used to study repetition priming. Another way is to present prime and lag like this: prime – lag – lag – target. This is done to study the strength of the prime effect.

Baselines in semantic priming studies are calculated as the RT to the unrelated words. When examining both facilitating and inhibitory effects it is necessary to have neutral words together with the related and unrelated words to calculate a baseline. The neutral words, non-words or just a string of the same letter must be chosen carefully to avoid interference with the related and unrelated words (McNamara, 2012).

Interval called Stimulus Onset Asynchrony (SOA) is used to study short presentations of the prime before target is presented. SOA is the interval from the prime is presented to the target is presented. This interval is called interstimulus interval outside the semantic priming literature (Donahoe & Palmer, 2004). Different lengths of SOA are used to study differences between automatic and strategic or attentional priming.

Semantic priming studies sometimes use response requirement to sample. This is not possible when using SOA that are shorter than RT to prime (Neely, 1991). This response refers to a keystroke. According to (McNamara, 2012)the participants are also instructed to silently read the prime. In behavior analysis, this reading would also be counted as a response to the sample.

The discovery by Meyer and Schvaneveldt (1971) was that related words would facilitate the responding to the following word. Neely (1976) found that primes could inhibit as well as facilitate the responding to the target when compared to a neutral word. Neely (1977) studied facilitation and inhabitation by showing wrong primes. Participant was told what word to expect and then an expected word, or a non-related word was presented. After the prime BUILDING, most of the trials had a target that was a body part. For the prime BODY, it was opposite, and buildings were the targets. The prime BIRD served as a control and had bird targets. These different groups and a neutral group were presented on three different SOA's, short, medium and long. Short was 250 ms, medium was 400 ms and long was 750 ms and 2000 ms were used as a control (Neely, 1977). The results showed facilitation for expected targets and inhabitation for unexpected targets. In other words for unexpected targets the reaction time was slower than for the neutral group There were also an increase in both facilitation and inhibition as a function of SOA. There was little or no facilitation or inhabitation for short SOA and much facilitation and inhabitation for long SOA. (McNamara, 2012; Neely, 1977). These results are used as evidence for two different processes called automatic and strategic priming. Automatic and strategic priming was suggested by Posner and Snyder (1975). Automatic priming is a fast acting process that is independent of the subjects' consciousness. Strategic priming is a slow process and is dependent of consciousness. Automatic priming cannot produce inhabitation while strategic priming can produce facilitation and inhabitation. (Posner & Snyder, 1975).

Automatic priming leads to the study of so called unconscious priming. McNamara (2012) starts by stating that the study of "unconscious" or "subliminal" priming is a very controversial issue (Quotation marks added by (McNamara, 2012). The controversy of this issue will not be discussed here, but procedures that study the phenomenon are relevant.

To study subliminal priming requires the prime to be visible for a very short time. Examples of short visibility are a prime latency of 17 to 50 ms (Draine & Greenwald, 1998; McNamara, 2012; Wentura & Frings, 2005). The interval for the prime can either be set by the experimenter, or the interval is set after a threshold setting procedure. Threshold setting is done by showing words to participants at short latencies and let them respond to whether they saw a word or not. When they report this at chance levels, the interval is set (Wentura & Frings, 2005).

Masking of the prime is also often used to decrease the visibility of the prime. This can be done with either backward masking, where a mask is presented after the prime, or sandwich masking where a mask is presented before and after a prime. Masks are usually a grid patterns (McNamara, 2012)

Draine and Greenwald (1998) use a procedure they call response-window to force rapid responding from the participants. Response window is also used by Wentura and Frings (2005) in experiment 3. This is similar to what is called limited hold in behavior analysis.

Another procedure found in behavior analysis is used by Draine and Greenwald (1998) in experiment 2. The response window is adjusted as a function of correct responding. Errors below or equal to 20% gave 33 ms less time to respond while more than 45% errors gave 33 ms more time to respond. Between 20% and 45% errors gave no change to length of response window. In behavior analysis, this procedure is called titration. Here it is the limited hold that is titrated.

Summary

Semantic priming study how reaction time to words varies as a function of different primes and how primes are presented. This is done by the use of many procedures that bear similarities with procedures from studies of stimulus equivalence. Barnes-Holmes et al. (2005) showed that participants that failed to respond in accordance with stimulus equivalence also did not show a priming effect for the same stimuli. These results support the study of derived relations as a model for semantic processes (Barnes-Holmes et al., 2005). The next part will focus on stimulus equivalence, procedures, results and explanations. Similarities between semantic priming and stimulus equivalence will be presented and discussed in the last part.

Stimulus equivalence

If we say that semantic priming studies how related words are, then we can say that stimulus equivalence studies how this relation is made. The field of stimulus equivalence was as semantic priming started in 1971. Sidman (1971) experimented with procedures that would teach a boy with mental retardation to read. The goal was to teach reading with meaning. Reading of words on another language in a foreign news paper would be reading without meaning. The boy knew how to relate spoken words to pictures of objects, but not to written words. He lacked the ability to tact the pictures or written words and could not match picture to written word or vice versa. After the training which consisted of selecting the correct written word after hearing the spoken word, he was able to perform above criteria for all relations; spoken word to written word, tact written word, tact picture, match written word to picture and match picture to written word (Sidman, 1971). In the discussion of the results Sidman (1971) asks if these results could be reproduced with arbitrary symbols.

Emergence of untrained relations under extinction conditions is a very good reason for studying stimulus equivalence (Arntzen, 2010). Not just the occurrence of emergent relations but under what conditions this occurs or do not occur. Stimulus equivalence is not a product of behavior; it is a way of responding, and can only be inferred (Sidman, 1992). If the participants have reached criteria for baseline relations they have learned that B1 is correct if A1 is sample and that C1 is correct if B1 is sample (the example is a LS training structure). Then they should, according to Sidman's (1994) "big bag" theory, be able to pass a test for symmetry (B1A1A2A3, C1B1B2B3), transitivity (A1C1C2C3) and equivalence (C1A1A2A3). Sometimes this does not happen. A problem that could have happened is that the baseline relations have deteriorated during testing, it has therefore become like a rule to mix baseline relations with test relations.

One reason for deteriorating baseline relations could be that the relations are fragile due to too little training (McIlvane, Serna, Dube, & Stromer, 2000)

There are three views about how to explain the phenomenon of stimulus equivalence. They are stimulus equivalence as a basic process (Sidman, 1992), naming (Horne & Lowe, 1996) and relation frame theory (RFT) Hayes (Hayes, Barnes-Holmes, & Roche, 2001).

Sidman (1992) proposed that we may have to view stimulus equivalence as a basic behavioral principle until there is more proof that non-humans are not able to form equivalence relations. A basic behavior principle is behavior that cannot be explained thoroughly by other existing principles. Reinforcement is an example of a behavior principle. It is not possible to explain why responding increases in probability by referring to other behavior principles.

Horne and Lowe (1996) present naming a basic unit of verbal behavior which is necessary to be able to respond correct to derived relations. Naming is a higher operant and consists of listener behavior, echoic behavior and tact. When naming is established, derived conditional responding or responding in accordance with equivalence is possible.

In relational frame theory (RFT) relational responding is a generalized operant based on a history of multi-exemplar training. Relational responding are in turn called relational frames and different frames have one or more of these three properties: mutual entailment, combinatorial entailment and transformation of function (Hayes et al., 2001).

The next section is an overview of different procedures from stimulus equivalence research. Their connection to semantic priming will be presented in the last part of this paper.

Stimulus equivalence procedures

Arntzen (2012) provides a review of the different training and testing parameters used in stimulus equivalence studies. The review focuses on variables that influence the establishment of experimenter defined classes and how test results are influenced by different parameters in the test. The current section will present a selection of the parameters for this review. The parameters will later be compared to similar parameters from semantic priming procedures. The parameters that is presented are: matching to sample (simultaneous or delayed), different training structures (Linear series, many-to-one and one-to-many), response requirement to sample stimulus (RRS), familiar or abstract stimuli and limited hold.

Studies of stimulus equivalence mostly use the matching to sample format. A sample is presented in the middle and comparison stimuli appear around the sample. Sidman and Tailby (1982) discuss the difference between conditional discrimination and matching to sample. If matching to sample is used to explain a relation between stimuli it has to prove that the relation passes a test for stimulus equivalence, in other cases the relation should be called conditional discrimination. If A1 then select B1 and not B2 Matching to sample can also be used as a name for the procedure used in the training and not to however to explain the relations.

Stimulus equivalence studies use three different ways to present sample and comparison stimuli. These are: simultaneous matching to sample (SMTS) or delayed matching to sample (DMTS) with either 0 sec delay or n sec delay. Arntzen (2006) and Bortoloti and de Rose (2012) have studied the difference between SMTS and DMTS and found that the equivalence yield are larger when there is a delay than when the matching is simultaneous.

Another presentation method that is seldom used is the go/no-go procedure in which the sample and comparison stimuli are presented together, and the participant responds to the compound according to a given rule (Grisante et al., 2013; Markham & Dougher, 1993).

The order of presentation of the direct trained relations will influence responding in accordance with equivalence. The importance of this is how the stimuli are connected. If A1 is trained to B1 and A1 is trained to C1, then A1 will be the node that connects B1 and C1. This is called sample as node or one-to-many (OTM) training structure. If the comparison stimuli functions as node then the training structure is called many-to-one (MTO) (Arntzen & Vaidya, 2008). According to Arntzen (2012) it is somewhat difficult to compare the results from studies that compare MTO and OTM due to differences in the other experimental parameters. The last training structure is called linear structure (LS). Here, A1 is trained to B1, and B1 is trained to C1, and B1 is the link or node between A1 and C1. This is the only structure where all tests for equivalence are possible. It is not possible to do separate tests for transitivity and equivalence in OTM or MTO. In these structures, the global equivalence test incorporates both transitivity and equivalence. The LS structure is the only structure where the nodal distance effect can be examined (Arntzen, Grondahl, & Eilifsen, 2010).

In matching to sample tasks, it is important for the result whether the participants attend to the sample stimuli or not. This is solved by either showing the sample for a give time period or by require a response to the sample stimulus. A study by (Arntzen, Braaten, Lian, & Eilifsen, 2011) showed that the requirement of a response to sample stimulus in helped the participants to learn the conditional discriminations faster. The stimuli used in stimulus equivalence studies must essentially be meaningless to the participant. This is done to make sure that the effects that found can be explained by parameters in the experiment and not due to a previous learning history with the stimuli. When familiar stimuli are presented early in the training, it will facilitate the establishment of direct trained relations (Arntzen, 2004; Fields, Arntzen, Nartey, & Eilifsen, 2012; Holth & Arntzen, 2000).

Some studies restrict the time available for responding to either sample or comparison (Arntzen & Haugland, 2012; Holth & Arntzen, 2000; Imam, 2001; Tomanari, Sidman, Rubio, &

Dube, 2006). This is called limited hold. Responses within the timeframe are recorded while responses outside the timeframe are treated as errors. This procedure is used to force the participant to respond quickly. This is usually done by adding the limited hold after training the direct relations as done in Tomanari et al. (2006) and Arntzen and Haugland (2012). Then the available time is reduced until a certain level is reached. This reduction of available time is called titration. Titration is the adjusting of limited hold based on the level of accuracy in the participants responding. Responding above the criteria decreases the time and responding below criteria increases the time. Titration can also be used in studies of DMTS. Here, it is the delay between the sample and comparison that is adjusted. If a long delay is the goal then responding to criteria will increase the delay while responding below criteria will decrease the delay.

There are other parameters that are important when studying stimulus equivalence but which have limited use when similarities with semantic priming are examined. Examples of these parameters are: the use of instructions, concurrent versus serialized presentation of training trials, programmed consequences and fading of programmed consequences.

Testing in stimulus equivalence studies is the measure of whether the stimuli have become equivalent. This is done by presenting trials with stimuli that are new to the participant. The stimuli are the same but, the presentation of the stimuli is new. In linear series, A is trained to B and B is trained to C. C has never been a sample and A has never been a comparison. When the transitive test C1A1A2A3 is presented this is the first time the participant sees that configuration of stimuli. Usually the number of correct derived relations in the test is used as a measure of whether the participants responds in accordance with equivalence (Dymond & Rehfeldt, 2001). Conditional discriminations which are trained before the test are also measured in the test. This is to make sure that a negative result for derived relations could be caused by too many errors in the direct trained relations (Green & Saunders, 1998)

Reports on reaction times are usually limited to reaction time after baseline training and early and late in the test. The usual pattern here is that reaction time to direct trained relations increases at the onset of test and decreases during testing. Reaction time to symmetry, transitivity and equivalence will typically be fastest for symmetry and slowest for equivalence. They also decrease from early to late in the test and keeping their initial rank. Nodal distance effect as studied by Fields, Adams, Verhave, and Newman (1990) is the effect in which reaction time increases as a function of number of nodes. In a linear structure with five members, the reaction time to 1-node relations (AC, BD, CE, CA, DB or EC) would be faster than 3-node relations (AE or EA). Other studies have reported no such distance effects. Reaction time early in training is rarely reported. Dymond and Rehfeldt (2001) suggest that reaction latency could be used as an additional measure in stimulus equivalence studies.

Summary

Stimulus equivalence is the study of how new relations emerge after a history of conditional discrimination training with seemingly meaningless stimuli. There are still many facets of the establishment of equivalence relations that need exploring. Studies like (Barnes-Holmes et al., 2005)and (Hayes & Bisset, 1998) could help shed light on some of these issues from the view of semantic priming.

Discussion

When Sidman wrote about conducting research in 1960, he listed five reasons for conducting experiments. These are to: evaluate hypotheses, indulge a curiosity about nature, try out a new method or technique, establish the existence of a behavioral phenomenon, and explore the conditions under which a phenomenon occurs (Sidman, 1960).

This part will discuss reasons for exploring phenomenon studied in semantic priming by using procedures from stimulus equivalence research, and to use techniques or procedures from semantic priming research on the study of stimulus equivalence. Sidman's reasons will be used as guidelines.

Procedures

As mentioned earlier two studies have used both SE and SP procedures. These are Hayes and Bisset (1998) and (Barnes-Holmes et al., 2005). Both tried to replicate the findings from semantic priming studies using stimulus equivalence procedures and arbitrary stimuli (constructed non-words). Hayes and Bisset (1998) examined mediating and episodic priming, but as mentioned earlier these are usually covered by literature on semantic priming. Then they used a test which tested for both stimulus equivalence and semantic priming. Hayes and Bisset (1998) replicated the procedures in Meyer and Schvaneveldt (1971) which were two-word presentation while Barnes-Holmes et al. (2005) used the single word lexical decision task. Both studies were successful in producing results similar to semantic priming studies. This provides evidence for claiming that the phenomenon that is studied by both semantic priming and stimulus equivalence is the same phenomenon. The difference is that the phenomenon is approached from different angles. Semantic priming tries to answer the question about how we store our knowledge, and does this by analyzing reaction times to different words and use these results to infer how the words must be stored to account for the differences in reaction times. While in stimulus equivalence the focus is how we learn to relate words and objects, in the absence of direct reinforcement.

Learning history

The choice of stimuli used in experiments is important in both SP and SE, but from different perspectives. In SP effort is put into counterbalancing the lists of words to avoid confound from repetition. The classes “related” and “unrelated” words from semantic priming studies are experimenter defined. Even if everyone would say that CAR and WHEEL are more related than CAR and LEMON, there are still unknowns when it comes to the participants learning history. The effect of this is reduced by comparing results across subjects. In a replication of Balota and Lorch (1986) done by Palmer and Katz (2005) they found a substantial overlap between related and unrelated words. The latencies to related words in their study ranged from 416 ms to 2150 ms with a standard deviation of 189 ms, and latencies for unrelated words ranged from 183 ms to 2250 ms with a standard deviation of 228 ms. This is variability that should be addressed according to (Palmer & Katz, 2005).

This problem is sought to be avoided in SE studies by making the learning history an explicit part of the experiment and the stimuli are chosen carefully. The participants are asked to sort the stimuli and also whether they know any of the stimuli. This is done to ensure that experimenter defined relations are not established before training. If the participant knows any of the stimuli they must be classified as familiar and will alter the conditions for the establishment of relations (Arntzen & Lian, 2010).

In both Hayes and Bisset (1998) and (Barnes-Holmes et al., 2005) the priming effect was found while using meaningless stimuli which means that the priming effect can be studied even after relatively short amounts of training.

Spreading activation with arbitrary stimuli

According to (Donahoe & Palmer, 2004) the presentation of a prime activates a pattern of interconnected neurons in the brain. The neurons in such an activation pattern consist of many subsets of neurons. When the brain reacts to a stimulus, the activation starts in a receptor subset and spreads through the other subsets connected to that stimulus. This activation does not happen instantly. It can take hundreds of milliseconds before the whole pattern is activated (Donahoe & Palmer, 2004). These activation patterns are interesting for semantic priming effects since a word will prime different targets according to how long the neurons have been active (Donahoe & Palmer, 2004). It is possible to argue that the findings of nodal distance by Fields et al. (1990) is the same phenomenon as being explained by the spread of activation. The model of such spreading activation proposed by Collins and Loftus (1975) would be possible to test by using arbitrary stimuli. This could be done by designing an experiment where two or more sets of equivalence classes are combined through a common stimuli as it was done in Sidman, Kirk, and Willson-Morris (1985), and test for the different parameters of spreading activation as mentioned by McNamara (2012, p. 13). If this could be done with typical adults while using arbitrary stimuli and experimenter defined classes, the theory would have a chance of being falsified. The ability to be falsified strengthens a model or theory. This research would probably require several studies.

Unconscious conditional discrimination

We know from studies of unconscious priming that it is possible to find effects of priming latencies, as short as 17 ms. A possible extension could be unconscious establishment of conditional discrimination. Would it be possible to learn arbitrary relations when given very little time? A cognitive psychologist might add: when given very little time to process the stimuli.

There are a few studies that have used very short latencies during testing for stimulus equivalence. These are in order of appearance Holth and Arntzen (2000), Tomanari et al. (2006) and Arntzen and Haugland (2012). All of these started training of conditional discrimination without restrictions in time. The restrictions in time or limited hold were added after all the classes were established.

To follow Sidman's (1960) suggestions it would be interesting to examine whether the phenomenon of semantic priming with very short prime duration, would extrapolate to the establishment of conditional discriminations. How short the latencies should be is difficult to determine as there would be individual differences, and a good way to determine them would be to have a threshold setting procedure as described by Wentura and Frings (2005). To ensure rapid responding, limited hold would be necessary as the earlier mentioned studies of short latencies and stimulus equivalence. The adjustment of the limited hold or response-window as a function of correct responding as done by Draine and Greenwald (1998) would further make sure that the settings were adapted to each participant.

Tomanari et al. (2006, p. 366) asks: "Even if reinforcement had been programmed during the tests, would the rapid rate of trial presentations have permitted the subjects to learn those new conditional discriminations at all?". The prediction from the research of semantic priming and stimulus equivalence would be; yes.

Closing remarks

In this paper, I have tried to show that there is great overlap in the subject matter between semantic priming and stimulus equivalence. There are also overlapping procedures used in research of semantic priming and stimulus equivalence.

The reason for this comparison of semantic priming and stimulus equivalence is not to try to merge the two research areas, but rather to show that there are many similarities, and that there could be collaboration or sharing when it comes to procedures and the methods used. This is the same point as Slocum and Butterfield (1994) make when they discuss the “schism between behavioral and cognitive analyses”. They stress the importance of contact between the two fields and that the researches in each field could learn from each other. When behavior analysis continues to explore more complex behavior, these areas could already have been examined by cognitive researchers, and it would be wise for behavioral researchers to build on this work (Slocum & Butterfield, 1994)

References

Arntzen, Erik. (2004). Probability Of Equivalence Formation: Familiar Stimuli And Training Sequence. *The Psychological Record, 54*(2), 275-291. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Arntzen, Erik. (2006). Delayed Matching to Sample: Probability of Responding in Accord with Equivalence as a Function of Different Delays. *The Psychological Record, 56*(1), 135-167. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Arntzen, Erik. (2010). Om stimulusekvivalens - Teoretiske betraktinger, oppsummering av en del empiri og noen praktiske implikasjoner. In S. Eikeseth & F. Svartdal (Eds.), *Anvendt Atferdsanalyse - Teori og praksis* (2 ed., pp. 100-138). Oslo: Gyldendal Norsk Forlag.

Arntzen, Erik. (2012). Training and Testing Parameters In Formation of Stimulus Equivalence: Methodological Issues. *European Journal of Behavior Analysis, 13*(1), 123-135. Retrieved from: http://www.ejoba.org/

Arntzen, Erik, Braaten, Live Fay, Lian, Torunn, & Eilifsen, Christoffer. (2011). Response-to-Sample Requirements in Conditional Discrimination Procedures. *European Journal of Behavior Analysis, 12*(2), 505-522. Retrieved from: http://www.ejoba.org/

Arntzen, Erik, Grondahl, Terje, & Eilifsen, Christoffer. (2010). The Effects of Different Training Structures in The Establishment of Conditional Discriminations and Subsequent Performance on Tests for Stimulus Equivalence. *The Psychological Record, 60*(3), 437-461. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Arntzen, Erik, & Haugland, Silje. (2012). Titration of Limited Hold to Comparison in Conditional Discrimination. *The Psychological Record, 62*, 243-262. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Arntzen, Erik, & Lian, Torunn. (2010). Trained and Derived Relations With Pictures Versus Abstract Stimuli as Nodes. *The Psychological Record, 60*(4). Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Arntzen, Erik, & Vaidya, Manish. (2008). The Effect of Baseline Training structure on Equivalence Class Formation in Children. *Experimental Analysis of Human Behavior Bulletin, 26*(1-8). Retrieved from: http://www.eahb.org/bulletin/bulletin-archives/

Balota, David A., & Lorch, Robert F. (1986). Depth of Automatic Spreading Activation: Mediated Priming Effects in Pronunciation but Not in Lexical Decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12*(3), 336-345. doi: 10.1037/0278-7393.12.3.336

Barnes-Holmes, Dermot, Staunton, Carmel, Whelan, Robert, Barnes-Holmes, Yvonne, Commins, Sean, Walsh, Derek, Stewart, Ian, Smeets, Paul M., & Dymond, Simon. (2005). Derived stimulus relations, semantic priming, and event-related potentials: testing a behavioral theory of semantic networks. *Journal of the Experimental Analysis of Behavior, 84*(3), 417-433. doi: 10.1901/jeab.2005.78-04

Battig, William F., & Montague, William E. (1969). Category norms of verbal items in 56 categories A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology, 80*(3, Pt.2), 1-46. doi: 10.1037/h0027577

Best, John B. (1995). *Cognitive Psychology* (4 ed.). St. Paul, MN: West Publishing Company.

Bortoloti, Renato, & de Rose, Julio C. (2012). Equivalent stimuli are more strongly related after training with delayed matching than after imultaneous matching: a study using the implicit relational assessment procedure (IRAP). *The Psychological Record, 62*, 41-54. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Collins, Allan M., & Loftus, Elizabeth F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*(6), 407-428. doi: 10.1037/0033-295X.82.6.407

Donahoe, John W., & Palmer, David C. (2004). *Learning and complex behavior*. Richmond MA: Ledgetop Publishing.

Draine, Sean C., & Greenwald, Anthony G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General, 127*(3), 286-303. doi: 10.1037/0096-3445.127.3.286

Dymond, Simon, & Rehfeldt, Ruth Anne. (2001). Supplemental Measures of Derived Stimulus Relations. *Experimental Analysis of Human Behavior Bulletin, 19*, 8-12. Retrieved from: http://www.eahb.org/bulletin/bulletin-archives/

Fields, Lanny, Adams, Barbara J., Verhave, Thom, & Newman, Sandra. (1990). The Effects of Nodality on the Formation of Equivalence Classes. *Journal of the Experimental Analysis of Behavior*, *53*(3), 345-358. doi: 10.1901/jeab.1990.53-345

Fields, Lanny, Arntzen, Erik, Nartey, Richard K., & Eilifsen, Christoffer. (2012). Effects of a meaningful, a discriminative, and a meaningless stimulus on equivalence class formation. *Journal of the Experimental Analysis of Behavior, 97*(2), 163-181. doi: 10.1901/jeab.2012.97-163

Green, Gina, & Saunders, Richard R. (1998). Stimulus Equivalence. In K. A. Lattal & M. Perone (Eds.), *Handbook of Research Methods in Human Operant Behavior* (pp. 229-262). New York: Springer.

Grisante, Priscila C., Galesi, Fernanda L., Sabino, Nathalí M., Debert, Paula, Arntzen, Erik , & McIlvane, William J. (2013). Go/No-Go Procedure with Compound Stimuli: Effects of

Training Structure on the Emergence of Equivalence Classes. *The Psychological Record, 63*, 63-72. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Gulan, Tanja, & Valerjev, Pavle. (2010). Semantic and related types of priming as a context in word recognition. *Review of Psychology, 17*(1), 53-58.

Hayes, Steven C., Barnes-Holmes, Dermot, & Roche, Bryan. (2001). *Relational Frame Theory: A post-Skinnerian account of human language and cognition*. New York: Kluwer Academic/Plenum.

Hayes, Steven C., & Bisset, Richard T. (1998). Derived Stimulus Relations Produce Mediated and Episodic Priming. *The Psychological Record, 48*(4), 617-630. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Holth, Per, & Arntzen, Erik. (2000). Reaction times and the emergence of class consistent responding: a case for precurrent responding? *The Psychological Record, 50*, 305-337. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Horne, Pauline J., & Lowe, C. Fergus. (1996). On the Origins of Naming and Other Symbolic Behavior. *Journal of the Experimental Analysis of Behavior, 65*(1), 185-241. doi: 10.1901/jeab.1996.65-185

Imam, Abdulrazaq A. (2001). Speed contingencies, number of stimulus presentations, and the nodality effect in equivalence formation. *Journal of the Experimental Analysis of Behavior, 76*(3), 265-288. doi: 10.1901/jeab.2001.76-265

Markham, Michael R., & Dougher, Michael J. (1993). Compound stimuli in emergent stimulus relations: Extending the scope of stimulus equivalence. *Journal of the Experimental Analysis of Behavior, 60*(3), 529-542. doi: 10.1901/jeab.1993.60-529

McIlvane, W. J., Serna, R. W., Dube, W. V., & Stromer, Robert. (2000). Stimulus Control Topography Coherence and Stimulus Equivalence: Reconciling Test Outcomes with Theory. In J. C. Leslie & D. Blackman (Eds.), *Experimental and Applied Analysis of Human Behavior*. Reno, NV: Context Press.

McKoon, Gail, & Ratcliff, Roger. (1979). Priming in episodic and semantic memory. *Journal of Verbal Learning and Verbal Behavior, 18*(4), 463-480. doi: http://dx.doi.org/10.1016/S0022-5371(79)90255-X

McNamara, Timothy P. (2012). *Semantic Priming : perspectives from memory and word recognition*. New York, NY: Psychology Press.

Meyer, David E., & Schvaneveldt, Roger W. (1971). Facilitation in Recognizing Pairs of Words: Evidence of a Dependence between Retrieval Operations. *Journal of Experimental Psychology, 90*(2), 227-234. doi: 10.1037/h0031564

Neely, James H. (1976). Semantic Priming and Retrieval from Lexical Memory: Evidence for Facilitatory and Inhibitory Processes. *Memory & Cognition, 4*(5), 648-654.

Neely, James H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106*(3), 226-254. doi: 10.1037/0096-3445.106.3.226

Neely, James H. (1991). Semantic Priming Effects in Visual Word Recognition: A Selective Review of Current Findings and Theories. In D. Besner & G. W. Humphreys (Eds.), *Basic Processing in Reading: Visual Word Recognition* (pp. 264-336). Hillsdale, NJ: Erlbaum.

Palmer, David C. (2009). Response strenght and the concept of the repertoire. *European Journal of Behavior Analysis, 10*(1), 49-60. Retrieved from: http://www.ejoba.org/

Palmer, David C., & Katz, Sara R. (2005). The Intraverbal Effects of Briefly Presented Verbal Stimuli. *VB News*, *5*(1), 4-8. Retrieved from: http://caiomigu.ipower.com/articles/vbnews5.pdf

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 55-85). Hillsdale,NJ: Erlbaum.

Sidman, Murray. (1960). *Tactics of Scientific Research : Evaluating Experimental Data in Psychology*. Sarasota, FL: Authors Cooperative, Inc.

Sidman, Murray. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research, 14*, 5-13.

Sidman, Murray. (1992). Equivalence relations: Some basic considerations. In S. C. Hayes & L. J. Hayes (Eds.), *Understanding Verbal Relations* (pp. 15-27). Reno, Nevada: Context Press.

Sidman, Murray. (1994). *Equivalence Relations and Behavior: A Research Story*. Boston, MA: Authors Cooperative.

Sidman, Murray, Kirk, Barbara, & Willson-Morris, Martha. (1985). Six-Member Stimulus Classes Generated by Conditional-Discrimination Procedures. *Journal of the Experimental Analysis of Behavior, 43*(1), 21-42. doi: 10.1901/jeab.1985.43-21

Sidman, Murray, & Tailby, William. (1982). Conditional Discrimination vs. Matching to Sample: An Expansion of the Testing Paradigm. *Journal of the Experimental Analysis of Behavior, 37*(1), 5-22. doi: 10.1901/jeab.1982.37-5

Slocum, T. A., & Butterfield, E. C. (1994). Bridging the schism between behavioral and cognitive analyses. *The Behavior Analyst*, *17*(1), 59-73. Retrieved from: http://www.ncbi.nlm.nih.gov/pmc/journals/557/

Tomanari, Gerson Y., Sidman, Murray, Rubio, Adriana, & Dube, William V. (2006). Equivalence classes with requirements for short response latencies. *Journal of the Experimental Analysis of Behavior*, *85*(3), 349-369. doi: 10.1901/jeab.2006.107-04

Wentura, Dirk, & Frings, Christian. (2005). Repeated Masked Category Primes Interfere With Related Exemplars: New Evidence for Negative Semantic Priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*(1), 108-120. doi: 10.1037/0278-7393.31.1.108

Effect of Pre-Training with Rapid Responding on Formation of Equivalence Classes

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Abstract

The purpose of this article is to do a systematical replication of Tomanari, Sidman, Rubio, and Dube (2006) and Arntzen and Haugland (2012) with a pre-training with identity matching where limited hold to sample and comparison are titrated to asymptotic level. The participants are given these levels and an additional 200 ms to establish conditionals discrimination with arbitrary stimuli. This was done with five participants and their limited hold to sample ranged from 400 ms to 700 ms and for comparison from 800 ms to 1100 ms. None of the participants were able to establish conditional discrimination to criteria, but there are evidence that two of them are able to establish conditional discriminations with very little time to respond.

Keywords: stimulus equivalence, pre-training, limited hold, asymptotic level

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Stimulus equivalence is a fascinating phenomenon. There are no doubt that humans are able to relate things, words and people in their environment to other things, words and people. But how important is this for us and is it really a effect of something else or must it be looked at as a basic stimulus function (Sidman, 1992). Derived responding in humans was early identified as a very interesting topic when studying human behavior (Green & Saunders, 1998; Hull, 1939). After Sidman's pioneer research in (1971) there has been a gradual increase in published studies of derived responding and stimulus equivalence (Arntzen, 2010). There are still fundamental questions that have not been answered. The most important is probably whether the ability to make derived responses is only possible for humans and not for non-humans (Donahoe & Palmer, 2004). Stimulus equivalence refers to the interchangeability of stimuli in accordance with the following properties: reflexivity, symmetry, transitivity and equivalence. These properties define different relations between the stimuli in a class. In the following example nine symbols (often Greek or Arabic letters) are divided by the experimenter into three classes (1, 2 and 3) with three members (A, B and C). The classes will be A1B1C1, A2B2C2 and A3B3C3. There is no way to categorize the stimuli in the correct classes just by looking at the stimuli. A linear series training structure is used to train the following relations: A1B1B2B3, A2B1B2B3, A3B1B2B3, B1C1C2C3, B2C1C2C3 and B3C1C2C3. Reflexivity is tested with these test trials: A1A1A2A3, A2A1A2A3 and A3A1A2A3 (the same for B and C trials). Symmetry is tested with these test trials B1A1A2A3, B2A1A2A3, B3A1A2A3, C1B1B2B3, C2B1B2B3 and C3B1B2B3. Transitivity is tested with these trials: A1C1C2C3, A2C1C2C3 and A3C1C2C3. Global equivalence tested with these trials C1A1A2A3, C2A1A2A3, C3A1A2A3. (Arntzen, 2012; Arntzen & Hansen, 2011; Sidman & Tailby, 1982).

The relations trained in the example above are called conditional discriminations. These relations must be established with as little interference from the experimenter as possible. At least if the goal is to study responding as a function of the procedure and not as a function of a verbal rule. It would be easier, instead of training the relations via conditional discrimination, to just tell a participant that these stimuli belong together in a class and those stimuli belong together in a class. Spencer and Chase (1996) tried to manipulate verbal rules to facilitate establishment of direct trained relations. If this happens unintentionally the study will not be about conditional discriminations but rule-governed behavior. Too minimize variations in what the different participants are told before an experiment and to avoid saying to much about the subject matter Written instructions are usually used in stimulus equivalence studies to avoid influencing the probability of establishing relations between stimuli. Information like “belong together”, “goes together”, “are related” would make the task much easier to the participants (Sidman, 1994; Spencer & Chase, 1996). Other studies have shown that humans are much less susceptible to alterations in experiments than non-humans (Shimoff, Catania, & Matthews, 1981).

Instead of explicitly telling participant what to do an alternative is to give them a pre-training with the same task. Buffington, Fields, and Adams (1997) showed that pre-training with arbitrary conditional discrimination facilitated the establishment of new arbitrary relations. Participants with prior training had fewer trials to criteria of direct trained relations and had also a higher outcome on responding in accordance with equivalence. The two last results was a function of how many arbitrary members in the pre-training stimulus set.

Studies show that we will easily form new relations between stimuli that are already related. This is also true for stimuli that are familiar to us, but which are not related in any way. Arbitrary relations between meaningless stimuli are the hardest (Bentall, Dickins, & Fox, 1993, experiment 1). The result from this experiment is explained with how the stimuli were named. The first group could be named on group level, while the second group of stimuli had individual names that had to be related. The third group had neither familiar names nor prior relations. In experiment 3 by Bentall et al. (1993) participants were trained with meaningless stimuli and got either a common name for groups of stimuli or individual names. They replicated the results from the first experiment since the stimuli with common names were related as they were associated. The stimuli with individual names still required many trials before criteria was met. Spencer and Chase (1996) found similar results as Bentall et al. (1993) when measuring speed and accuracy. There was a difference in results for symmetry trials. Which they argues could be explained by having response requirement to sample. Bentall et al. (1993) did not have response requirement to sample. Studies have shown that a response requirement to sample can facilitate the establishment of direct trained relations. (Arntzen, Braaten, Lian, & Eilifsen, 2011). When presentation of sample is fixed an there are no requirement for response to sample it is possible that the participant fills the time with behavior that are unavailable to the experimenter(Spencer & Chase, 1996). This is good arguments for conducting studies with available time as an independent variable. By forcing the participants to respond there will be less time for so called mediating behavior.

The study by Bentall et al. (1993) showed differences according to how stimuli was related prior to an experiment. Semantic priming is a way to study the relatedness of stimuli (words). There are recent studies that suggest that stimulus equivalences is a good way to study semantic priming (Barnes-Holmes et al., 2005; Haimson, Wilkinson, Rosenquist, Ouimet, & McIlvane, 2009). In semantic priming the research questions are related to the difference in reaction time between related and unrelated words and how to influence this reaction time (McNamara, 2012). Reaction time is also examined within stimulus equivalence. Spencer and Chase (1996)argues that the strength of an equivalence relation consist of measures of both response speed and response accuracy. This view is supported by Dymond and Rehfeldt (2001).

If we look at reaction times from studies that report this, we can see that the reaction time is longer in the initial stages of establishing baseline relations (Tomanari et al., 2006). This is not strange and is true with all learning of new skills. The connection between speed and accuracy is the basis for precision teaching where rapid performance and accuracy is better than accuracy alone (Johnson & Layng, 1996). In stimulus equivalence studies the reaction times under the establishment of conditional declines as more and more of the experimenter defined relations are learned. Whether the participant learns the experimenter defined relations or have made other relations the reaction time will still decrease (Holth & Arntzen, 2000; Mandell, 1997). When the participant reaches the test for derived relations the reaction time increases for symmetry, transitivity and equivalence trials. The RT for baseline trials increases temporarily at the onset of test but then decreases to previous level. Fields and Adams (1993) and Fields, Landon-Jimenez, Buffington, and Adams (1995) analyses these differences to say something about how close the stimuli are related. Short RT translates to a strong relationship, and the relationship weakens as the RT increases. In most studies of stimulus equivalence the participants usually has unlimited time under the initial establishment of the conditional discriminations. Reaction time is a dependent variable. If you limit the time available for responding by enforcing a limited hold reaction time will function as an independent variable (and dependent?). Arntzen and Haugland

(2012) searched for studies of stimulus equivalence and limited hold and found just these (Holth & Arntzen, 2000; Imam, 2001, 2003; Spencer & Chase, 1996; Tomanari et al., 2006). After this the only new study is the study by Arntzen and Haugland (2012).

Brief overview of the following studies: Holth and Arntzen (2000), Tomanari et al. (2006) and Arntzen and Haugland (2012). There are some procedural differences but all studies use arbitrary stimuli and one-to-many procedure, and all had thinning of programmed consequences before testing.

Holth and Arntzen (2000) experiment 3 used a serialized one-to-many procedure to train BA and BC relations for three classes in ten students. They used simultaneous matching to sample with 90% criteria for mastery. After establishing direct trained relations there were a phase with a 2 s limited hold until 100% for a block of 24 trials. The first half of testing had the same limited hold of 2 s. While the last part had no limited hold restrictions. Five participants met criteria for training and short latencies. None responded in accordance with equivalence on the first half of the test. One responded in accordance with equivalence for both halves of the second half, while two only met criteria for the second half of the second half. Number of training trails for the participants who passed the training varied from 202 to 480 trials, and for those who did not pass it was 574 to 737 trials. They also found an increase in RT to sample when restrictions was put on responding to comparison

Tomanari et al. (2006) used a serialized one-to-many procedure to train AB and AC relations for four classes of arbitrary stimuli in five adult participants. Matching to sample with response requirement to sample and 0s delay before presentation of comparison. When baseline relations was established limited hold was introduced and time available were gradually reduced. Trials to criterion (95%) were reached after a mean of 1709 trials (Range 1224-2960). Limited hold was titrated down to asymptotic level in phase II. Criteria for asymptotic level were two consecutive failures of reduction within criteria for correct responding (95%). All participant required many trials to complete this phase. The mean was 12267 trials (range 9144-14328). In phase III consequences were faded from 100% to 0%. Phase IV was the test phase where combined equivalence trials (BC and CB) were tested first and then symmetry trials (BA and CA) were tested. Both combined equivalence and symmetry test was interspersed with baseline trials (AB and AC). In the test phase there was a combination of extinction and differential feedback, both for trained and untrained relations After titration in phase II the mean levels of LH for sample and comparison was 460 ms and 1260 ms. The mean actual levels were 240 ms and 680 ms for sample and comparison respectively. In testing three participants responded in accordance with equivalence. One of these responded below criteria for at least one test block.

The study by Arntzen and Haugland (2012) is a systematic replication of Tomanari et al. (2006) with some changes in the procedure. Some changes are due to the software and some changes due to unclear descriptions in Tomanari et al. (2006). Phase I was serialized OTM training of AB trials and AC trials for three classes. There were matching to sample 0 sec delay, response requirement to sample and 400 ms inter-trail interval. There was no titration or LH for sample only for comparison. Comparison was titrated down to 1200 ms which is the lowest LH to comparison in Tomanari et al. (2006). Reduction of LH levels was done automatic by the software in Arntzen and Haugland (2012) and manually in Tomanari et al. (2006). Before testing the participants were exposed to a mean of 1510 trials (range 666-2934) while in Tomanari et al. (2006) the mean before testing was 15587 trials (range 11088–20928). The number from Tomanari et al. (2006) should be somewhat larger due to one extra class but it is reasonable to say that it is a big difference in exposure for trial types in the two studies.

In all these studies there has been an establishment of conditional discrimination with unlimited time available and when the participant reaches the criteria, usually 90% correct in a block the limited hold contingencies are enforced. The time available for responding decreases as long as a function of accuracy above 90%, except in Holth and Arntzen (2000). This is loosely the same procedure as any precision teaching program. First establish a degree of accuracy then decrease response time (Johnson & Layng, 1996). Tomanari et al. (2006, p. 366) asks a question under the discussion regarding presentation of probe trials for derived relations "Even if reinforcement had been programmed during the test, would the rapid rate of trial presentation have permitted the subjects to learn those new conditional discriminations at all?". But under establishment of baseline relations they've had unlimited time available for so called precurrent responding (Holth & Arntzen, 2000). Precurrent responding is any behavior that facilitates correct responding (Catania, 2007). Precurrent responding or mediated responses take time. A meta study by Verhaeghen, Steitz, Sliwinski, and Cerella (2003) looked at several different task with dual performance. Dual performance is somewhat similar to conditional discrimination. The participant will have to respond to the sample and select one of the comparison based on which sample he saw. One of the studies in the meta study, McDowd and Craik (1988) examined the difference in reaction time for young and old persons on both a single and dual visual discrimination task. They found approximately 200 ms difference between the single and dual task. These results are similar to what has been found in eye tracking studies where 200 ms to 300 ms is the time needed for a person to attend to a given stimuli (Salthouse & Ellis, 1980)

Arntzen and Haugland (2012) proposes a couple of interesting alterations to their study to further investigate under what circumstances the formation of conditional discriminations and derived relations would be made impossible. One suggestion is pre-training with rapid responding and using very short time available to respond from the beginning of training conditional discriminations. Pre-training would facilitate later performance by being familiar with the experiment situation (Buffington et al., 1997). Another suggestion is to record responses that fall right on the outside of the limited hold. These responses could tell us whether relations between stimuli are being formed or not.

Based on the suggestions from Arntzen and Haugland (2012) and the prior studies using short latencies, titration of limited hold and titration to asymptotic there are arguments for setting up the following experiment:

Pre-training with identity matching with colors, where limited hold to sample and comparison will be adjusted to asymptotic level. Then use these limited hold values as a starting point for conditional discrimination. In addition to the limited hold values from the pre-training 200 ms will be added to the limited hold for the difference in tasks, based on McDowd and Craik (1988) and Salthouse and Ellis (1980). After conditional discrimination training with these parameters limited hold levels will increase as a function of correct responding until direct trained relations are established.

This experiment poses the following research question:

What is the effect of pre-training of rapid responding using identity matching on the establishment of conditional discrimination under short limited hold contingencies? And subsequently how will the pre-training with rapid responding affect the responding when the participants are give more time available to respond.

Method

Figure 1 is a flowchart of the different phases in the study and Table 1 is an overview over probability of programmed consequences, minimum trials and criteria. There are several terms used to depict the different parts of the study and to avoid confusing the reader Figure 9 explains the different terms graphically.

Participants

Five participants were recruited via personal contacts. The participants were aged from 29 to 44 with a mean of 35 and there were four women and one man (see Table 2). They were told that the experiment was about memory, problem solving, language and semiotics, and that their task was to respond to stimuli on a computer touch screen. The participants were paid 100 nkr pr hour and this money would be paid whether they finished the experiment or chose to leave. They read and signed the consent form before the start of the experiment. Since all of the participants were familiar with typical smartphones which uses touch screen for input, there were no need for pre-training with touch screen. Nevertheless were they given a brief demonstration of how the screen responded to different types of touch (hard or soft; knuckle, nail or fingertip) this was done to avoid the problems that occurred with the first participant.

Apparatus and Setting

The experiment was run at two different locations. Settings were made as similar as possible. There was a cubicle in both locations. In location 1 it was approximately 1,5m times 1,5m and in location 2 it was approximately 1,7m times 2,3m. Inside the cubicle there was a chair and a table (location 1 1,4m width, 0,4 m depth and location 2 1,6m width, 0,8m depth). The experiment was run on a HP EliteBook 8730w with Intel®Core™2 Duo CPU P880 2.66GHz and Windows 7 operating system. The laptop was connected to a LG Flatron T1710 17inch touchscreen. Screen resolution for touch screen was 1280x960. During the experiment the participants only saw the touch screen as the computer was located outside the cubicle. The matching to sample software was developed by Cognitive Science Partners and in collaboration with professor Erik Arntzen. The version number was 1.0.9.3. Figure 3 shows one trial as it were on the screen.

Stimuli

The stimuli used in the experiment are shown in Figure 4. It was the same stimuli as in Arntzen and Haugland (2012). The size of the stimuli is also the same as in their study approximately 3cm x 3cm on the screen. The stimuli in the identity phase (1A, 1B and 1C) were approximately 5 cm x 5 cm on the screen.

Design

This is a systematical replication of (Tomanari et al., 2006) and (Arntzen & Haugland, 2012). Both the previous studies used an AB-design where titration of limited hold levels followed conditional discrimination training without limited hold. This study will also be an AB-design. It could be called a BA-design as the experiment condition is presented prior to the condition that most resembles training as usual. AB-design is also called a quasi-experimental design as it has no innate way to show experimental control.

Procedure

The procedure consisted of five phases (see Figure 1). Phase 1A and 1B was identity matching with colors where the time for sample and comparison was titrated down separately. Phase 1C was a phase with identity matching with fixed time similar to phase 1A and 1B to ensure rapid responding. Phase 1C was run at the beginning of each day. Phase 2 were training of baseline relations with limited hold and in phase 3 the training of baseline relations continued with increasing time available for responding. After reaching criteria in phase 3 there was a test for derived relations. If there was a failure to reach criteria in test, the test was repeated three times. Between tests there was a reestablishing of baseline trials. To reduce fatigue, sessions were limited to two phases of 720 trials. This was true for both phase 2 and 3 (see figure 1). Phase 1A and 1B was always run on a separate day. There was a limit of maximum two days break between two sessions. The only exception was between phase 1A and 1B, and phase 2. Phase 1C would ensure that the limited hold was retrained. In all the phases there was an option to take a break after 36 trials. Each experiment day (Figure 2) consisted of maximum two training cycles of 720 trials, which translates to 20 sessions á 36 trials. After 10 sessions the participants were instructed to take a longer break. This break was used for toilet breaks or fetching beverage. Since the phases were to be terminated or altered after 720 trials it was necessary to keep track of how many trials had been run. The participants were instructed to state out loud whenever the computer asked them to take a break. They would then take a short break as needed (to crack knuckles or stretch fingers), or take a longer break when instructed to do so. The experimenter kept track of the breaks with pen and paper. Data recorded by the software showed that there were no errors regarding number of trials when this was compared to the manually recorded breaks.

Phase 1A. This was the phase were the time available for responding to sample stimulus was titrated down to asymptotic level. This was done using the same program as was later used for establishing baseline relations. The stimuli in this phase were colored squares (red, green and yellow). None of the participants were colorblind. The stimuli were presented in a matching-to-sample format with a 0-sec delay. The initial time available for sample was 2000 ms. The titration block was one of each trial type (A1B1, A1C1, A2B2, A2C2, A3B3, A3C3). Since all the stimuli were identical the different trial types are just used so that the program would run properly. Mastery criteria was set to 80% this allows one error in each titration block of six. Under pilot testing the criteria was 90% and it took very long time (more than one hour) for the participants to reach a steady state. To avoid fatigue the criteria was set to 80%. Steady state was calculated by the program using the following parameters. The initial value for the limited hold to sample was 2000 ms and there were 6 trials per block. If there were 5 or more correct in the block the LH was decreased by 100 ms or increased by 100 ms with 4 or less correct. After 50 blocks the program started to look for a pattern consisting of two pairs of blocks with decreasing and increasing LH when this was found the program kept the LH steady for two blocks. If there were less than 5 correct in one of the two steady blocks the pattern was considered failed and the computer started to look for the next occurrence of pairs. If the two steady blocks were mastered the program went in to testing. Since the test was not needed the researcher ended the experiment and the participant was asked to take a break.

The way steady state is used here differs from the way steady state is used in books about research design like Sidman (1960). In this paper steady state refers to a set response pattern that the software looks for while the participants are working.

Phase 1B

In this phase the limited hold levels for the comparison stimuli was titrated down to asymptotic level. This was done using the same stimuli and procedure as in phase 1A. The only difference being that the limited hold for sample was fixed on the time found in phase 1A with the addition of 200 ms. The initial value for comparison was 2000 ms. When the asymptotic level was calculated after two pairs of decreasing and increasing and two steady blocks the program went into testing. Testing was not needed in this phase either so the experiment was stopped by the experimenter.

Determine limited hold values. After completion of phase 1A and 1B, the limited hold levels were determined. This was set to be the steady state level plus 200 ms. If a participant reached steady state at 800 ms in phase 1A the limited hold level for response to sample in phase 2 would be 1000 ms. The addition of 200 ms was done to ensure that the participants could maintain responding for about one hour.

Phase 1C. Before phase 2 and phase 3 there was a retraining of rapid responding. Phase 1C was identity matching with the limited hold levels set after completion of phase 1A and 1B. This was done to make sure that the participant could maintain the rapid responding. Phase 1C consisted of one six blocks of 30 trials (5 of each trial type) with an 80% mastery criterion. There was also a thinning of consequences in this phase. The first block had 100% feedback, and then feedback was faded to 75%, 50%, 25%, and 0% before the test block also with 30 trials. This was done to make the program stop without interference from the experimenter. In the test phase the LH was kept at the same value as in the training. The thinning of consequences in this phase was done to familiarize the participants with the thinning that they were informed would happen later in the study.

Phase 2. Phase 2 was run on the second experiment day after phase 1C had been run. This was the phase for establishing baseline relations with LH in place for both sample and comparison. The stimuli (see Figure 4) consisted of three classes with three members. The training structure was one-to-many or sample as node and the training order was concurrent presentation of the stimuli. In concurrent presentation all relations are trained at once. This means that AB trials and AC trials are presented in random order. The different trial types with sample first and correct comparison underlined: A1<u>B1</u>B2B3, A1<u>C1</u>C2C3, A2B1<u>B2</u>B3, A2C1<u>C2</u>C3, A3B1B2<u>B3</u>, A3C1C2<u>C3</u>, In serialized presentation, the AB trials are trained to mastery before the AC trials occur. It is not clear how concurrent presentation versus serialized presentation influences the establishment of conditional discrimination (Arntzen, 2012), but recent finding suggest that concurrent presentation is more difficult than serialized (Eilifsen & Arntzen, 2013, April). The reason for choosing concurrent presentation over serialized presentation was issues with the software and how titration blocks were calculated. The presentation of the trials was similar to phase 1A and 1B with the exception of the arbitrary stimuli. The sample stimuli were presented in the middle of the screen and the comparisons appeared in three of the corners with one blank corner. The comparison stimuli were placed in random order on the screen. The blank corner also changed location. There was a response requirement to sample stimulus with limited hold from phase 1A. The training blocks in phase 2 were 30 trials with a criterion of 90%. Feedback was initially 100% and faded to 75%, 50%, 25% and 0% when criterion of 90% were reached. Phase 2 was run for 720 trials which is the equivalent of 20 sessions á 36 trials. If the participant did not reach thinning of consequence before reaching 720 trials, phase 2 was ended and the participant continued with phase 3. If fading was reached before 720 trials, phase 2 would be run until 1440 trials. 1420 1440 trials was the maximum limit of trials per day. The only reason for deviating from this was if the participant had reached fading or test in phase 3.

Phase 3. Phase 3 was run on day three of the experiment. As day 2 it started with phase 1C to retrain fast responding. The difference from phase 2 is that time available for response to comparison was titrated. We still titrated down, but failure to reach criteria of 90% would increase the LH with 100ms. So we would see an increase in LH until the participant showed consistent correct responding. The same steady state levels as phase 1A and 1B was used. Two pairs up/down and two in row. In phase 3 there were the same criteria for breaks as in phase 2. Phase 3 was run for 720 trials with additional 720 trials for participants that reached thinning of consequences. Thinning is usually started when correct responding is above 90%. When titration of limited hold is used, correct responding above 90% will reduce time available for responding, which in turn may bring correct responding below 90%. This procedure will give the participants more training on baseline trials than a regular MTO procedure.

Programmed consequences

In the establishment of conditional discrimination there was 100% programmed consequences. In both phase 2 and 3 there was a fading of feedback at these intervals: 75%, 50%, 25% and 0%. Feedback was given as blue text on white background “1 point” and “0 point”. The points were added up in the bottom right corner of the screen. Under fading of feedback, the total score was only visible when points were received. The points served no other purpose than to help the participant keep track of their performance.

Deviation from the procedure

For one of the participants (7910) the fading of reinforcement in phase 3 went straight from 75 % to 25 %. This was an error that occurred when the parameters was loaded.

Data collection

All collection of data was done by the software. The software recorded which comparison that were selected and the reaction time. Responses outside the limited hold window were also recorded until the onset of the next trial as suggested in Arntzen and Haugland (2012) This was done to be able to find out whether the participants choose the correct comparison when it was too late. These responses would receive the feedback “0 point” and should not contribute to the establishment of the defined relations.

Test for derived relations

The test for derived relations was run directly after reaching criteria of 90% in the 0% fading of feedback phase. Test was run under extinction. The limited hold in test was 2500 ms which was the same as Arntzen and Haugland (2012) and Holth and Arntzen (2000). One test block was 90 trials which consisted of 30 baseline trials which tested the AB and AC relations, 30 symmetry trials which tested BA and CA relations and combined test which tested BC and CB relations.

Results

The main findings are that none of the participants were able to reach criteria under fixed time limited hold conditions with short latencies (see phase 2 in figure 5, 6, 7 and 8). In phase 3 when limited hold were increased with 100 ms for each block below 6 out 6 correct, all participants were able to establish experimenter defined relations (see phase 3 in figure 5, 6, 7 and 8). Under test for derived relations four of five participants passed the test. One participant passed the first test (see Table 3). Even if the participants was not able to reach criteria for correct responding as shown in the phase 2 part of figure 5, 6, 7 and 8, some of the relations formed very rapidly in phase 3. The results also show that the increase in LH levels had little effect on the RT. This is shown in the bottom part of figure 5, 6, 7 and 8. The participants continued to respond rapidly even when the limited hold increase as a function of their responding. The only exception from this would be participant 7908 (figure 7).

Further presentation of the results will start with the pre-training for all participants. Then establishment of direct trained relations for each participant. First for participants #7908 and #7909, then #7906 and #7907 and last participant #7910. The reason for this grouping is that there are some similarities which benefit from a joint presentation. Last results from test and categorization task will be presented.

Phase 1A and 1B - Titration of limited hold levels

The result from pre-training with identity matching is shown in table 4. There are just small variations in asymptotic levels. Asymptotic level for sample range from 200 ms to 500 ms. The number of blocks to reach steady state ranged from 57-87. One block was 6 trials and criteria for decreasing the LH level was 5 of 6 correct. For comparison the asymptotic level ranged from 600-900, and number of blocks to steady state ranged from 56-69. Minimum number of blocks was 55 or 330 trials. Two of the participants reached criteria for steady state faster on sample and for the three others steady state for comparison was reached faster.

Participant 7909 reached steady state at just 200 ms, this participant managed to reach criteria when LH was just 100 ms which resulted in LH for the next block to be set at 0 ms. When this happened the sample were shown (or not shown) for 0 ms. Since there were no visible sample the participant couldn’t respond to sample and the LH was increased to 100 ms. This happened two times.

Participant 7906 had some problems with responding during phase 1B and had difficulties reaching steady state. This resulted in two days of pre-training with identity matching. The first day phase 1B was terminated after 1080 trials which are 30 breaks á 36 trials. The second day phase 1B was terminated after 720 trials. The reason for not terminating day 1 after 720 was that results from pilots showed that steady state could occur just after 720 trials. On day 2 the termination was done to avoid fatigue. LH to comparison was manually set to 700 based on a rough mean estimate of raw data. Close inspection of the data showed that the participant was close to steady state at 700 ms and 1100 ms. The participant complained that the screen did not register the touches. Due to this the screen was cleaned in the long breaks. This was not done for any other of the participants. The results in phase 1C for participant 7906 showed that 900 ms was manageable when you subtract the trials where comparison was timed out.

Phase 2 – conditional discrimination with fixed LH

None of the participants were able to reach criteria in phase 2. Almost all of the participants reacted with what you could call nervous laughter at the beginning of phase 2. They had just completed phase 1C in which they matched colors. After the initial surprise they said something like “I don’t have enough time to look at the stimuli so I’m just choosing something”. These statements were not collected systematically.

The bar graphs in figure 4 show the percentage correct of trials where a response is emitted before onset of inter-trial-interval. Responses within the limited hold are shown in the grey bars and responses outside the limited hold but before onset of inter-trial-interval are shown in black bars. The responses that lie outside the limited hold are scored as incorrect by the software but which stimuli that is chosen and the reaction time is collected.

For two of the participants #7908 and #7910 we can see a gradual increase in correct responding. This gradual increase is followed by a similar increase in responses outside limited hold. For participant 7909 we can see a larger increase in responses outside limited hold than for correct responses within limited hold. Participant 7907 have a slight increase in correct responses both within and outside limited hold. Participant 7906 is the only one with a decrease in correct responses outside limited hold. This participant also had the lowest amount of responses outside limited hold at only 36 responses. For the other participants this was much higher #7907 had 114 trials, #7908 had 239 trials, #7909 had 104 trials and #7910 had 114 trials outside LH before onset for inter-trial interval.

There were some variations in RT during the fixed LH in phase 2. Participant 7906 responded faster in the second half of phase 2. He had a LH of 900 and RT in the first half was 573 mean of median and 508 mean of median in the second half. Participants 7908, 7909 and 7910 used more time in the second half. For participant 7907 there was no change.

Phase 3 - More time available to respond

Top part of figures 5, 6, 7 and 8 shows reaction time (open squares) and percentage correct (filled circles) from phase 2 and phase 3. Participant 7909 had just 216 trials in phase 3 until he reached criteria for steady state and continued with fading. Participant 7908 had just one phase 3, while the rest had more than one phase 3. In phase 3 the titration rapidly gave the participants more time to respond.

Participant 7906: Had no increase in correct responding until the middle of the first phase 3 (see top figure 5). Criteria was not reached and phase 3 was restarted which gave a dip in correct responding before it increased and had a mean above 90% for the last half of the second phase 3. Reaction time increased from a mean after phase 2 of 508 ms to 1270 ms in the second half of the first phase 3. In the second phase 3 RT decreased in the second half to a mean of 1019 ms.

Participant 7907: Had gradually more correct during phase 2 and two runs of phase 3. The reaction time showed the same pattern with gradually more time used. From a mean of 847 ms in the first half of phase 2 to a mean of 1642 ms in the second half of the second phase 3. This participant had manually set LH.

Participant 7908: Showed a very rapid shift in correct responding from phase 2 to phase 3. Mean correct responding in second half of phase 2 were 26%, while it was 82% in the first half of phase 3. Reaction time increased slightly during phase 3. Mean of 1090 ms in the first half and 1206 ms in the second half.

Participant 7909: Showed a rapid increase in correct responding and had only 216 trials in phase 3. The increase in reaction time was from 979 ms in the first half of phase 3 to 1242 ms in the second half.

Participant 7910: This was the only participant that needed two restarts of phase 3. Three runs of phase 3 total. The percent correct had a gradual increase during phase 2, and was rather steady at around 80% for the first two runs of phase 3. This participant had the fastest responding during all the runs of phase 3 compared to all the other participants. Figure 10 is a matrix with distribution of responses to different trial types. The A-stimuli are samples and B and C stimuli are comparisons. It is mainly selecting B3 when A2 is sample and selecting B2 when A3 is sample that causes most of the errors.

Titration of limited hold to steady state

In phase 3 the limited hold was increased and decreased as a function of correct responding. Correct responding at 90% or above decreased the limited hold by 100 ms. In this phase the size of the block was 6 trials. 5 of 6 correct equals 83.3 %. So to decrease the limited hold the participant must respond correct 6 of 6 trials. The bottom part of figure 5, 6, 7 and 8 shows limited hold (dashed line) levels and reaction time (solid line) for all participants and all phases.

For participant 7906 the limited hold levels increases until the participant reaches a point where the percentage correct stays above 90% (Figure 5 bottom), then we can see a slow decrease. Since the participant didn’t reach fading before 720 trials, the training cycle was ended and a phase 3 was restarted. In the next training cycle #7906 managed to reach steady state and continued with fading and test. Since fading was reached this cycle continued until completed testing which were 1314 trials.

Participant 7907 also had two training cycles with phase 3 (Figure 6 bottom). At the end of the last training cycle fading was reached, but this was not discovered before the training was ended that day. The last 18 trials were fading trials. Participant 7907 reaches 90% correct just at the end of the second run of phase 3 and also reaches steady state almost at the same time. Steady state requires four blocks with two pairs of above/below 90% and stability for two blocks.

As mentioned earlier participant 7908 had a very rapid increase in correct responding when given more time to respond as show in Figure 7. Figure 9 also show that #7908 had an increase in correct responses outside the limited hold levels. Limited hold levels for #7908 do not rise above 1900 ms and steady state is reached at 1600 ms. (Figure 7 bottom left).

Participant 7909 also had a rapid increase in correct responding after onset of phase 3 (figure 7 bottom right). The limited hold levels reach the highest point at 2700 which is also where criteria for steady state were met.

The rise in LH for participant 7910 is slightly slower than for 7907 (Figure 8 bottom). The level of correct responding is fairly steady just below 90% for the two first cycles of phase 3. When phase 3 is started for the third time, correct responding is around or above 90%. This time LH is 2200 ms at the most and a criterion for steady state is met at 1600 ms.

The number of trials in phase 3 is as following for each participant: 1428(#7906), 1422(#7907), 564(#7908), 216(#7909) and 2124(#7910).

Reaction time and trial types in test for derived responding

Here are the results from the test phase. They will be presented for each participant. The test was a combined test where direct trained trials were interspersed with symmetry and equivalence trials. Test was run under extinction. Reaction times are presented in figure 11, and equivalence class formation in table 3.

Participant 7906: Direct trained (DT) relations were intact in both tests. Symmetry relations had 26 correct in the first test and 28 in the second. Equivalence relations were intact at 27 correct in the first test and 29 in the second. In the first test RT for direct trained relations was faster during the 5 first than under fading of feedback and increased quite a bit to the last 5 DT trials. There is also a small increase from DT to 5 first to 5 last in the second test. RT for symmetry (SY) show very little difference from 5 first to 5 last in both tests. RT for equivalence (EQ) trials show a slight increase in test one and a slight decrease in test two.

Participant 7907: This participant had three tests and failed to respond according to equivalence on all tests. DT relations were intact for the last two tests. Symmetry relations increased increase through all tests: 16 in the first, 18 in the second and 23 in the third. The same happened for equivalence relations, 4 in the first, 12 in the second and 19 in the third. #7907 had the longest RT during test of all participants. RT for the last 5 of DT, SY and EQ there is a pattern of gradually increasing RT that is shown in many studies. The participant sorted the cards correct during the post categorization.

Participant 7908: Passed on the first test. During the 5 first trials RT for SY was larger than both DT and EQ. for the five last trials there were the same pattern as in both #7906 and #7907.

Participant 7909: Had two tests. Direct trained were intact in both tests. Symmetry and equivalence increased from 26 and 25 to 28 out 30 for both relations. The RT for this participant during the first test show very little variation. This also holds for the first five of the second test. For the last five in the second test RT for SY are larger than for EQ and DT has the shortest RT.

Participant 7910: Direct trained relations and equivalence relations were intact in both tests. Symmetry trials increased from 26 to 27 correct. The second test for this participant had the shortest RT of all participants. The median for both SY and EQ trials were below 1000 ms. RT for DT trials was a higher (1029 and 1201ms). For the first test the RT was higher.

Discussion

This study is an attempt to answer a question from Tomanari et al. (2006) about whether it is possible to make conditional discriminations with very little time available for responding. The first question was how pre-training with identity matching and limitation on time to respond would influence the training of conditional discriminations. The next question was how the participants would adjust the responding when they later had more time to respond.

The results show clearly that some of the participants (#7908 and #7909) were able to respond in accordance with the experimenter defined relations even with restrictions in time. This analysis is based on the rapid shift in correct responding between phase 2 and phase 3, and on the data collected outside the limited hold. None of the participants were successful in reaching the experimenter set criteria for completing training of conditional discriminations or responding in accordance with the experimenter defined relations within the allotted number of trials. But since there were a fixed amount of trials in phase 2, it is possible to speculate about what would happen if the training had continued for extended time.

Thinking speed and motor response speed

How fast is it possible to make a selection on a touch screen when you don’t have to think about what to select? The pre-training in this experiment used matching of colors as a way to train the participants to respond fast. For typical adults the matching of colors will be a task that requires very little time to do. But the person nevertheless has to do several things or needs to respond to several stimulus changes. First he must respond to the sample, and then when the sample disappears he must in some way decide which of the comparisons that are similar to the no longer visible sample and select the comparison he chooses. Adults have a long learning history with colors and it would be reasonable to assume that if we had presented a task where a participant had to solve a math problems (like 6+7 and 8+11) while simultaneously matching colors, these to task would not come in conflict. But a task where they simultaneously had to solve math problems and do conditional discriminations would be increasingly more difficult (Arntzen & Vie, Under review). The point is that we when the task are dissimilar we can do them simultaneously but other task will interfere and lower the rate of responding for both tasks. From semantic priming studies we know that the time spent “attending” to the stimuli can be pushed very low and the priming effect would still be found (Draine & Greenwald, 1998; McNamara, 2012). Draine and Greenwald (1998) argues that the limited hold (response-window) procedure shifts attention from performance to accuracy and this explains the subliminal priming. In other words when the participants responds quickly by default the attention is more susceptible to short prime durations. This would not qualify as a valid behavior analytical explanation. Even if the prime too short for the participants to notice it and they claim to not have seen it and respond accordingly in a test, the stimulus must still function as a discriminative stimuli or establishing operation for quick responding to the target. There is much evidence in stimulus equivalence research (Arntzen & Haugland, 2012; Imam, 2001; Tomanari et al., 2006) and fluency research (Johnson & Layng, 1992, 1996) which show that when performance is accurate it is possible to increase the speed of responding a great deal.

The participants were pre-trained to respond quickly and were also told to respond as quickly as possible in the instruction. The effect of this to events may have inhibited the increase in response time in phase 3. All participants kept on responding quickly even when given several seconds long limited holds (see bottom part of figure 5, 6, 7 and 8). This effect would be predicted rather accurately by studies like Shimoff et al. (1981). Experiments (Catania, Shimoff, & Matthews, 1989) have shown that humans have great difficulties adjusting to changes in contingencies after learning a rule. In Shimoff et al. (1981) continued to follow a rule of low rate button press even when the contingencies was changed. In this experiment the participants were told to make their selection as fast as possible. They got 0 points for all responses that were either wrong or outside the limited hold window. In Arntzen and Haugland (2012) there was a possibility in the program to give "Too late" as feedback. It is likely that this possibility could have made the participants more sensitive to the change in limited hold interval. Then they would know which responses that were errors and which that were timed out.

Since this is an AB-design the important point of interest is the change from fixed limited hold to titrating limited hold. For three of the participants (7908, 7909 and 7910) the data for phase 2 fixed limited hold show very little overlap with phase 3 when looking at percentage correct. The graph for percentage corrects for participant 7906 show a late change in trend and much overlap early in the phase. There is a more rapid increase in reaction time. Participant 7907 has almost similar trend in percentage correct for both phases. The reaction time follows the increase in percentage correct. Participant 7908 and 7909 both have a rapid increase in percentage correct. Participant 7908 has less increase in reaction time than 7909. Participant 7910 show an upward trend in percentage correct in phase 2 and this trend stop when phase 3 starts.

Usually in an AB-design a delayed change in dependent variable is interpreted as the intervention didn't have effect. But in this case we must look at it from the opposite angle. The supposed effect of the intervention was to investigate whether it was possible to establish conditional discriminations with very short time available for responding. When the change is delayed we must conclude that the conditional discriminations did not form. If the change is rapid the conditional discriminations must have been formed even if the time available to respond was very short and the errors were due to the fact that the participant did not have time to press but knew what the correct response would be. So when the limited hold was increased the percentage correct quickly rose to 90-100% as the relations were already learned. We see this effect in participant 7908 and 7909. For participant 7906 the conditional discriminations were established during phase 3 (see figure 5 top).

If a group design had been used with more replications per participant, an ABA and BAB design there would make the case stronger for extrapolating data from this experiment. To just turn the independent variable or limited hold on and off while using the same stimulus set would just give the effect of rapid correct responding found in both Tomanari et al. (2006) and Arntzen and Haugland (2012). Several replications of an AB-design or five in this experiment is also a way to show experimental control. Alas not as good as a experimental design.

All the participants used the same computer and touch screen. The experiment was conducted at two locations and an effort was made to make the two places as similar as possible. There was no excessive noise in either location. And the same experimenter was present at both locations. The results from pre-training show no systematic difference (table 4). The same goes for number of titrating trials and the asymptotic level after DT trials (table 4).

None of the participants had participated in an experiment before. The whole experiment situation and the fact that they knew little about what was interesting to the experimenter could in an experiment like this lead to an increase in reaction time. An assumption based on that they know that they will get points for correct responding and that it is natural to try to do as good as possible. But in this experiment they are forced to respond since no response also gives zero points. This facilitates response variation which increases probability of correct responding.

To define a correct and incorrect response is straight forward. But when time restrictions are placed on the response the definition of a correct response is narrowed. A correct response must be emitted within the time limit to be counted as correct. Correct responses outside the limited hold are incorrect as defined by the procedure, but they are still a part of the same process (Catania, 1973). The important contingencies in this experiment are the stimuli, the time constraints and the programmed consequences. The presentation of programmed consequences increases the probability that the participant chooses the correct comparison. Sometimes this happens within the limited hold and often the responses are delivered outside the limited hold. These responses result in the feedback 0-points. In the beginning of the session the participant will not know if the feedback is due to too slow responding or that the response is incorrect. This could have slowed down the establishment of direct trained relations.

Did the short latencies prohibit the development of conditional discrimination?

If we return to what Tomanari et al. (2006, p. 366) hypothesized; that the rapid rate of trial presentation would make it difficult to establish new relations. Indeed it was difficult but we have data from participants 7908 and 7909 that strongly suggest that they were able to establish the direct trained relations under with very short time to respond. Since the participants where moved to another phase if they did not reach fading we cannot say anything about whether they would have reached criteria eventually. This is also true for the other participants. What would have happened if phase 2 had been longer? For the two that showed development of classes we probably would have seen more correct responding both within and outside limited hold. Since the criteria for moving to fading was 90% this necessary would take very long time. The bars in figure 4 shows that participant 7908 and 7910 were able to make conditional discriminations with feedback and limited hold on 900 ms and 1000 ms respectively. These limited hold values are lower than 1200 ms and 1300 ms which are the values used by the participants in Tomanari et al. (2006). But clearly the limited hold inhibits the establishment of conditional discriminations. Arntzen and Hansen (2011) used serialized OTM with 3 classes and 3 members. All six participants with these parameters established baseline training with 180 to 225 trials. The participants who had 3 classes and 6 members used from 630 to 720 trials.

Suggestions for replications and further research

In this study pre training with identity matching was done with colors. Colored squares are easier to discriminate than black and white symbols. A study by (Spencer & Chase, 1996) used uppercase and lowercase letters in their pre-training. This would be more like the symbols used in most equivalence studies and this could make the pre-training of limited hold more realistic. It could be a problem that since an uppercase ‘A’ and a lowercase ‘a’ are different we are in fact teaching the participant what to do in the next phase. One solution is to use letters of different fonts and use lowercase letters that share similar properties like b, d, p and q. Another suggestion is to have a gradual increase of fixed LH and reduce the cycle length. Pre-training with letters, and give no extra time for conditional discrimination. Have a fixed limited hold for 240 trials, then increase the fixed limited hold by 100 ms per 240 trials.

References

Arntzen, Erik. (2010). Om stimulusekvivalens - Teoretiske betraktinger, oppsummering av en del empiri og noen praktiske implikasjoner. In S. Eikeseth & F. Svartdal (Eds.), *Anvendt Atferdsanalyse - Teori og praksis* (2 ed., pp. 100-138). Oslo: Gyldendal Norsk Forlag.

Arntzen, Erik. (2012). Training and Testing Parameters In Formation of Stimulus Equivalence: Methodological Issues. *European Journal of Behavior Analysis*, *13*(1), 123-135. Retrieved from: http://www.ejoba.org/

Arntzen, Erik, Braaten, Live Fay, Lian, Torunn, & Eilifsen, Christoffer. (2011). Response-to-Sample Requirements in Conditional Discrimination Procedures. *European Journal of Behavior Analysis, 12*(2), 505-522. Retrieved from: http://www.ejoba.org/

Arntzen, Erik, & Hansen, Steffen. (2011). Training Structures and the Formation of Equivalence Classes. *European Journal of Behavior Analysis, 12*(2), 483-503. Retrieved from: http://www.ejoba.org/

Arntzen, Erik, & Haugland, Silje. (2012). Titration of Limited Hold to Comparison in Conditional Discrimination. *The Psychological Record, 62*, 243-262. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Arntzen, Erik, & Vie, Aleksander. (Under review). On the role of distracters in delayed matching to sample. *The Psychological Record*.

Barnes-Holmes, Dermot, Staunton, Carmel, Whelan, Robert, Barnes-Holmes, Yvonne, Commins, Sean, Walsh, Derek, Stewart, Ian, Smeets, Paul M., & Dymond, Simon. (2005). Derived stimulus relations, semantic priming, and event-related potentials: testing a behavioral theory of semantic networks. *Journal of the Experimental Analysis of Behavior, 84*(3), 417-433. doi: 10.1901/jeab.2005.78-04

Bentall, Richard P., Dickins, David W., & Fox, Stephen R. A. (1993). Naming and equivalence: Response latencies for emergent relations. *The Quarterly Journal of Experimental Psychology Section B, 46*(2), 187-214. doi: 10.1080/14640749308401085

Buffington, Dawn M., Fields, Lanny, & Adams, Barbara J. (1997). Enhancing equivalence class formation by pretraining of other equivalence classes. *The Psychological Record*, *47*(1), 69-96. Retrieved from: http://search.proquest.com/docview/212671296?accountid=26439

Catania, A. Charles. (1973). The Concept of the Operant in the Analysis of Behavior. *Behaviorism, 1*(2), 103-116. Retrieved from: http://www.jstor.org/stable/27758804

Catania, A. Charles. (2007). *Learning (4th ed)* (4 ed.). Cornwall-on-Hudson, NY: Sloan Publishing.

Catania, A. Charles, Shimoff, Eliot, & Matthews, Byron A. (1989). An Experimental Analysis of Rule-Governed Behavior. In S. C. Hayes (Ed.), *Rule-Governed Behavior: Cognition, Contingencies, and Instructional Control* (pp. 119-150). New York: Plenum Press.

Donahoe, John W., & Palmer, David C. (2004). *Learning and complex behavior*. Richmond MA: Ledgetop Publishing.

Draine, Sean C., & Greenwald, Anthony G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General*, *127*(3), 286-303. doi: 10.1037/0096-3445.127.3.286

Dymond, Simon, & Rehfeldt, Ruth Anne. (2001). Supplemental Measures of Derived Stimulus Relations. *Experimental Analysis of Human Behavior Bulletin*, *19*, 8-12. Retrieved from: http://www.eahb.org/bulletin/bulletin-archives/

Eilifsen, Christoffer, & Arntzen, Erik. (2013, April). *Effects of Serialized and Concurrent Training in Matching-to-Sample Procedures.* Paper presented at the NAFO-seminar 2013.

Fields, Lanny, & Adams, Barbara J. (1993). Are Stimuli in equivalence classes equally related to each other? *The Psychological Record, 43*(1), 85. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Fields, Lanny, Landon-Jimenez, Donna V., Buffington, Dawn M., & Adams, Barbara J. (1995). Maintained Nodal-Distance Effects in Equivalence Classes. *Journal of the Experimental Analysis of Behavior, 64*(2), 129-145. doi: 10.1901/jeab.1995.64-129

Green, Gina, & Saunders, Richard R. (1998). Stimulus Equivalence. In K. A. Lattal & M. Perone (Eds.), *Handbook of Research Methods in Human Operant Behavior* (pp. 229-262). New York: Springer.

Haimson, Barry, Wilkinson, Krista M., Rosenquist, Celia, Ouimet, Carolyn, & McIlvane, William J. (2009). Electrophysiological Correlates of Stimulus Equivalence Processes. *Journal of the Experimental Analysis of Behavior, 92*(2), 245-256. doi: 10.1901/jeab.2009.92-245

Holth, Per, & Arntzen, Erik. (2000). Reaction times and the emergence of class consistent responding: a case for precurrent responding? *The Psychological Record, 50*, 305-337. Retrieved from: http://thepsychologicalrecord.siuc.edu/index.html

Hull, Clark L. (1939). The problem of stimulus equivalence in behavior theory. *Psychological Review, 46*(1), 9-30. doi: 10.1037/h0054032

Imam, Abdulrazaq A. (2001). Speed contingencies, number of stimulus presentations, and the nodality effect in equivalence formation. *Journal of the Experimental Analysis of Behavior, 76*(3), 265-288. doi: 10.1901/jeab.2001.76-265

Imam, Abdulrazaq A. (2003). Assessing Transfer of Respons Speed and Nodality via Conditional Discriminations. *Experimental Analysis of Human Behavior Bulletin, 21*, 1-7. Retrieved from: http://www.eahb.org/bulletin/bulletin-archives/

Johnson, Kent R., & Layng, T. V. Joe. (1992). Breaking the structuralist barrier: Literacy and numeracy with fluency. *American Psychologist, 47*(11), 1475-1490. doi: 10.1037/0003-066X.47.11.1475

Johnson, Kent R., & Layng, T. V. Joe. (1996). On Terms and Procedures: Fluency. *The Behavior Analyst, 19*(2), 281-288. Retrieved from: http://www.ncbi.nlm.nih.gov/pmc/journals/557/

Mandell, Charlotte C. (1997). Stimulus Equivalence and Meaning: The Influence of Verbal Behavior. In C. C. Mandell & A. McCabe (Eds.), *The Problem of Meaning - Behavioral and Cognitive Perspectives* (pp. 81-116). New York: Elsevier Science B.V.

McDowd, Joan M., & Craik, Fergus I. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance, 14*(2), 267-280. doi: 10.1037/0096-1523.14.2.267

McNamara, Timothy P. (2012). *Semantic Priming : perspectives from memory and word recognition*. New York, NY: Psychology Press.

Salthouse, Timothy A., & Ellis, Cecil L. (1980). Determinants of Eye-Fixation Duration. *The American Journal of Psychology, 93*(2), 207-234. doi: 10.2307/1422228

Shimoff, Eliot, Catania, A. Charles, & Matthews, Byron A. (1981). Uninstructed human responding: Sensitivity of low-rate performance to schedule contingencies. *Journal of the Experimental Analysis of Behavior, 36*(2), 207-220. doi: 10.1901/jeab.1981.36-207

Sidman, Murray. (1960). *Tactics of Scientific Research : Evaluating Experimental Data in Psychology*. Sarasota, FL: Authors Cooperative, Inc.

Sidman, Murray. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research, 14*, 5-13.

Sidman, Murray. (1992). Equivalence relations: Some basic considerations. In S. C. Hayes & L. J. Hayes (Eds.), *Understanding Verbal Relations* (pp. 15-27). Reno, Nevada: Context Press.

Sidman, Murray. (1994). *Equivalence Relations and Behavior: A Research Story*. Boston, MA: Authors Cooperative.

Sidman, Murray, & Tailby, William. (1982). Conditional Discrimination vs. Matching to Sample: An Expansion of the Testing Paradigm. *Journal of the Experimental Analysis of Behavior, 37*(1), 5-22. doi: 10.1901/jeab.1982.37-5

Spencer, Thomas J., & Chase, Philip N. (1996). Speed Analysis of Stimulus Equivalence. *Journal of the Experimental Analysis of Behavior, 65*(3), 643-659. doi: 10.1901/jeab.1996.65-643

Tomanari, Gerson Y., Sidman, Murray, Rubio, Adriana, & Dube, William V. (2006). Equivalence classes with requirements for short response latencies. *Journal of the Experimental Analysis of Behavior, 85*(3), 349-369. doi: 10.1901/jeab.2006.107-04

Verhaeghen, Paul, Steitz, David W., Sliwinski, Martin J., & Cerella, John. (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging*, *18*(3), 443-460. doi: 10.1037/0882-7974.18.3.443

Table 1

Table 1 shows an overview of which trial types are presented in each phase, minimum trials, criterion and thinning of programmed consequences

Blocks	Probability of programmed consequenses (%)	Minimum Trials	Criterion	Criterion %
Pre training				
1. Identity Matching (colors) titrating LH to sample	100	330	5/6	80
2. Identity Matching (colors) titrating LH to comparison	100	330	5/6	80
Phase 2				
1. Concurrent AC and BC with LH (max 720 trials)	100	30	27/30	90
2. Mixed Trials AC, BC	75	30	27/30	90
3. Mixed Trials AC, BC	50	30	27/30	90
4. Mixed Trials AC, BC	25	30	27/30	90
5. Mixed Trials AC, BC	0	30	27/30	90
Phase 3 (restart after 720 trials)				
1. Concurrent AC and BC with LH titrating to asymtotic level	100	30	6/6	90
2. Mixed Trials AC, BC	75	30	27/30	90
3. Mixed Trials AC, BC	50	30	27/30	90
4. Mixed Trials AC, BC	25	30	27/30	90
5. Mixed Trials AC, BC	0	30	27/30	90
Testing (max 3 tests)				
Test block with DT trials(AC, BC),	0	30	27/30	90
SYM trials(CA, CB),	0	30	27/30	90
and EQ trials(BC, CB) randomly intermixed	0	30	27/30	90

Table 2

Table 2 shows participant data, location and computer used.

Participant	Gender	Age	Status	Location	Computer
7906	F	38	Employed	1	15
7907	F	44	Employed	1	15
7908	F	33	Employed	2	15
7909	M	29	Student	2	15
7910	F	31	Student	2	15

Table 3.

Table 3 shows results from test for derived relations. One test block consist of 90 trials, with 30 direct trained trial (DT), 30 symmetry trials (SY) and 30 combined equivalence trials (EQ).

	Equivalence Class Formation								
	Test 1			Test 2			Test 3		
ID	DT	SY	EQ	DT	SY	EQ	DT	SY	EQ
7906	**30/30**	26/30	**27/30**	**29/30**	**28/30**	**29/30**			
7907	20/30	16/30	4/30	**28/30**	18/30	12/30	**29/30**	23/30	19/30
7908	**28/30**	**30/30**	**29/30**						
7909	**30/30**	26/30	25/30	**29/30**	**28/30**	**28/30**			
7910	**30/30**	26/30	**27/30**	**30/30**	**27/30**	**30/30**			

Table 4.

Table 4 shows the results from the pre-training with titration of asymptotic levels. Limited hold level is asymptotic level plus 200 ms. The table also show number of titration trials and results of titration in phase 3. For participant 7906 the asymptotic level was manually set.

	Phase 1				Phase 3	
	Asymptotic level		Limited hold level		Titrate to asymptot	
Participant	Phase 1A	Phase 1B	Sample	Comparison	Trials	Level
7906	500	700*	700	900	1428	2300
7907	500	900	700	1100	1422	9800
7908	400	700	600	900	564	1600
7909	200	600	400	800	216	2700
7910	500	800	700	1000	2124	1600

Figure Captions

Figure 1. Flowchart of the procedure with some key parameters and decision points which determined change of phase. Phase 1C is not depicted on the flowchart. It was done prior to all runs of phase 2 and phase 3.

Figure 2. An overview of what the different parts of the study are called. To avoid confusion

Figure 3. Flowchart showing one trial from presentation of sample to inter-trial interval and the different feedback scenarios.

Figure 4. Stimuli used in the experiment was the same stimuli as in Arntzen and Haugland (2012). A-stimuli served as sample during training.

Figure 5. Reaction times, percent correct and limited hold for participant 7906. Top: RT and percent correct for phase 2 and 3. Below: RT and LH. Median across 60 trials.

Figure 6. Reaction times, percent correct and limited hold for participant 7907. Top: Reaction time and percent correct for phase 2 and 3. Below: RT and LH. Median across 60 trials.

Figure 7. Reaction times, percent correct and limited hold for participants 7908 and 7909. Top: Reaction time and percent correct for phase 2 and 3. Below: RT and LH. Median across 60 trials.

Figure 8. Reaction times, percent correct and limited hold for participant 7910. Top: Reaction time and percent correct for phase 2 and 3. Below: RT and LH. Median across 60 trials.

Figure 9. Shows percent class consistent responding within and outside LH. Timed-out responses to sample or comparison are removed from these bars.

Figure 10. Matrix of responses within limited hold for all trial types for participant 7910. NR is timed out responses.

Figure 11. Reaction times during 5 last direct trained trials, 5 first test trials and 5 last test trial for each relation.

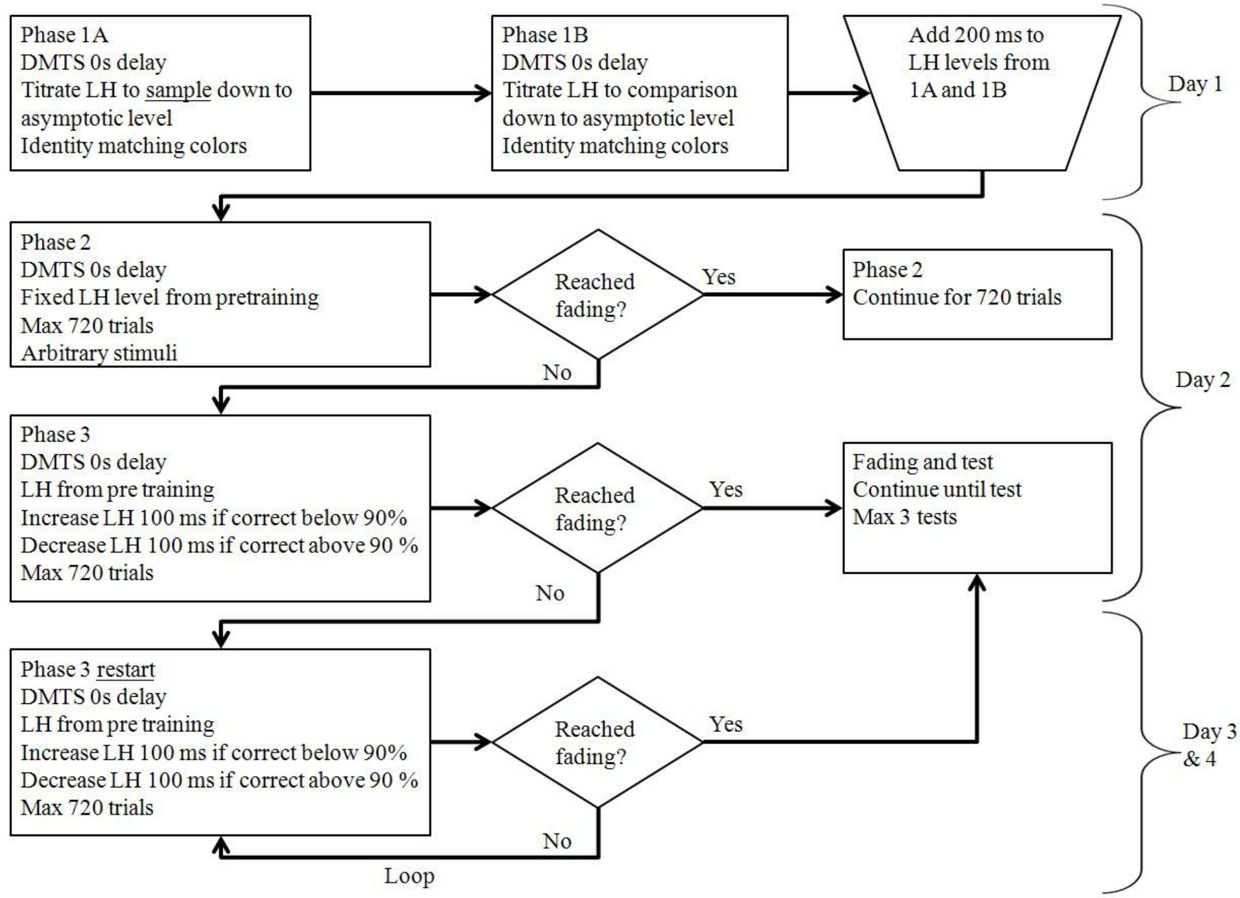
Phase 1A
DMTS 0s delay
Titrate LH to sample down to asymptotic level
Identity matching colors
Phase 1B
DMTS 0s delay
Titrate LH to comparison down to asymptotic level
Identity matching colors
Add 200 ms to LH levels from 1A and 1B
Day 1
Phase 2
DMTS 0s delay
Fixed LH level from pretraining
Max 720 trials
Arbitrary stimuli
Reached fading?
Yes
No
Phase 2
Continue for 720 trials
Day 2
Phase 3
DMTS 0s delay
LH from pre training
Increase LH 100 ms if correct below 90%
Decrease LH 100 ms if correct above 90 %
Max 720 trials
Reached fading?
Yes
No
Fading and test
Continue until test
Max 3 tests
Phase 3 restart
DMTS 0s delay
LH from pre training
Increase LH 100 ms if correct below 90%
Decrease LH 100 ms if correct above 90 %
Max 720 trials
Reached fading?
Yes
No
Loop
Day 3 & 4

Figure 1.

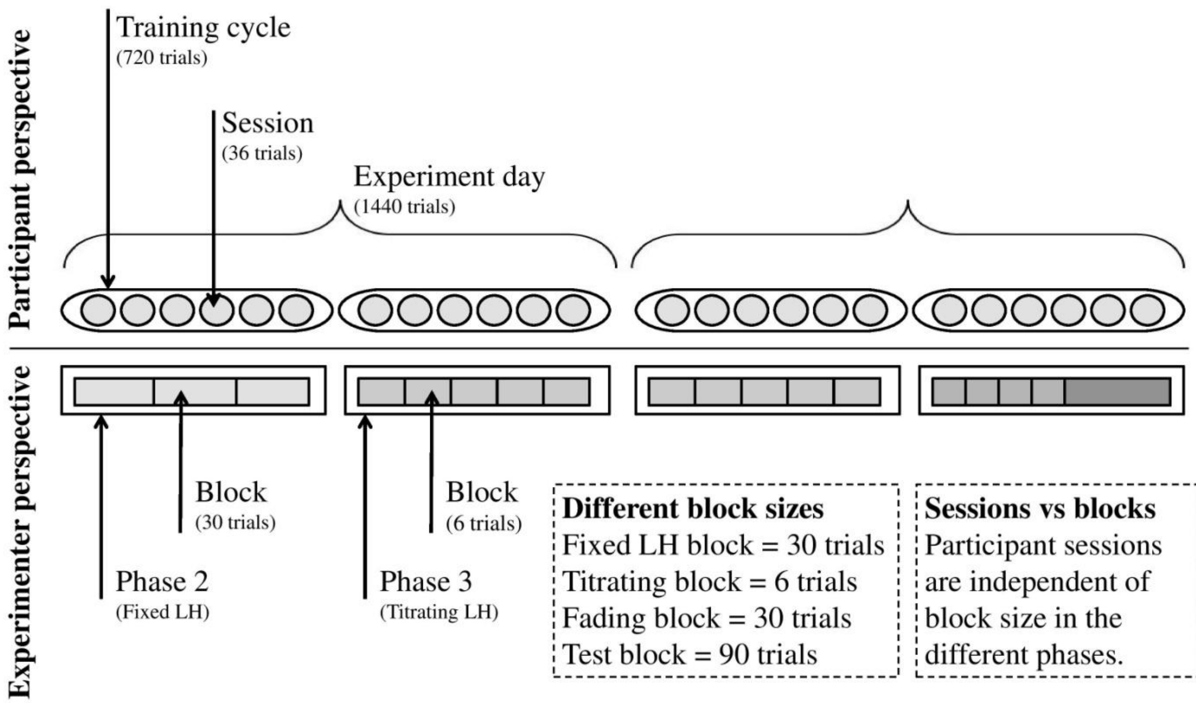
Participant perspective
Training cycle
(720 trials)
Session
(36 trials)
Experiment day
(1440 trials)
Experimenter perspective
Block
(30 trials)
Block
(6 trials)
Phase 2
(Fixed LH)
Phase 3
(Titrating LH)
Different block sizes
Fixed LH block = 30 trials
Titrating block = 6 trials
Fading block = 30 trials
Test block = 90 trials
Sessions vs blocks
Participant sessions are independent of block size in the different phases.

Figure 2

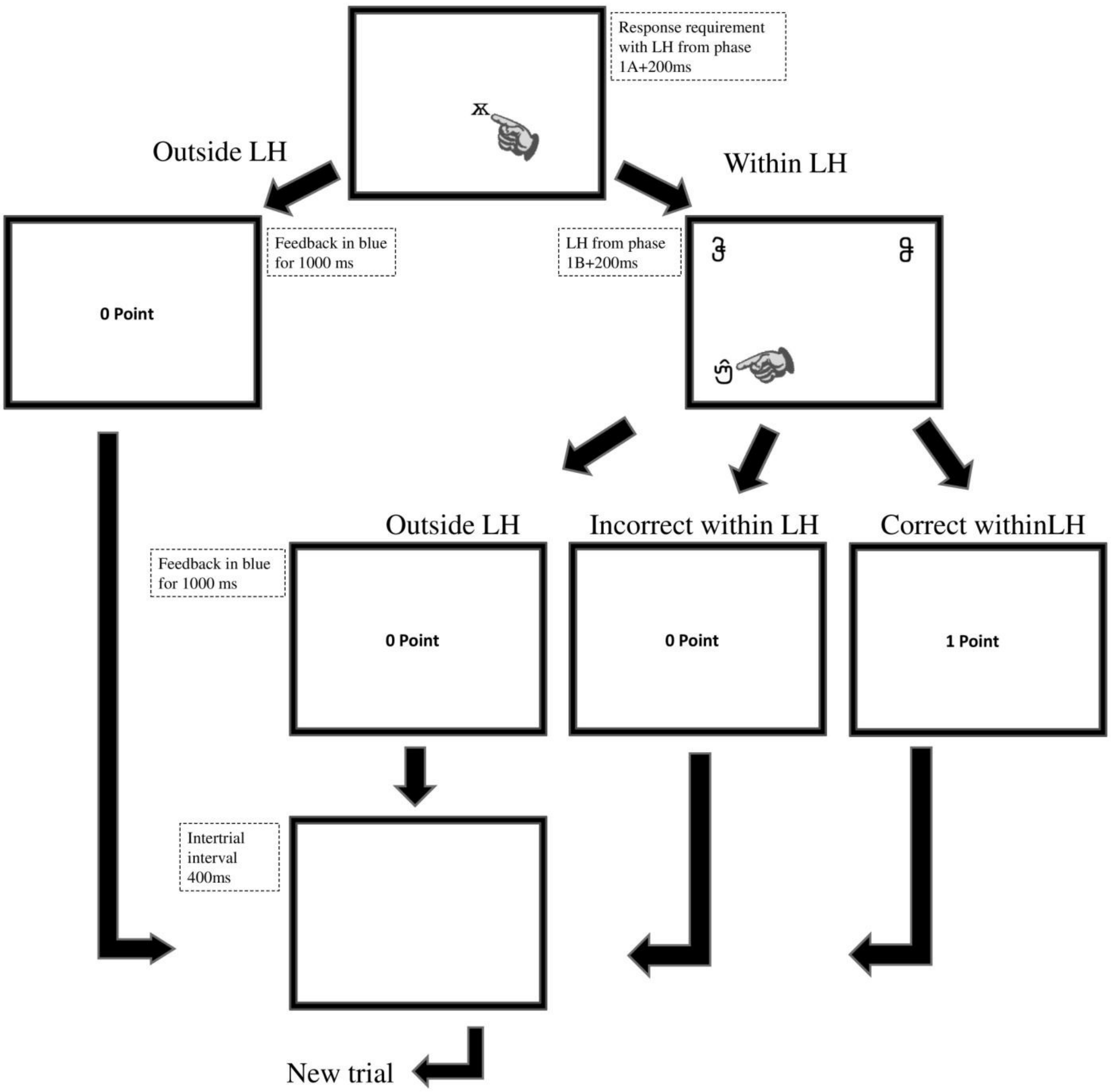
Response requirement with LH from phase 1A+200ms
Outside LH
Within LH
Feedback in blue for 1000 ms
LH from phase 1B+200ms
0 Point
Outside LH
Incorrect within LH
Correct withinLH
Feedback in blue for 1000 ms
0 Point
0 Point
1 Point
Intertrial interval 400ms
New trial

Figure 3.

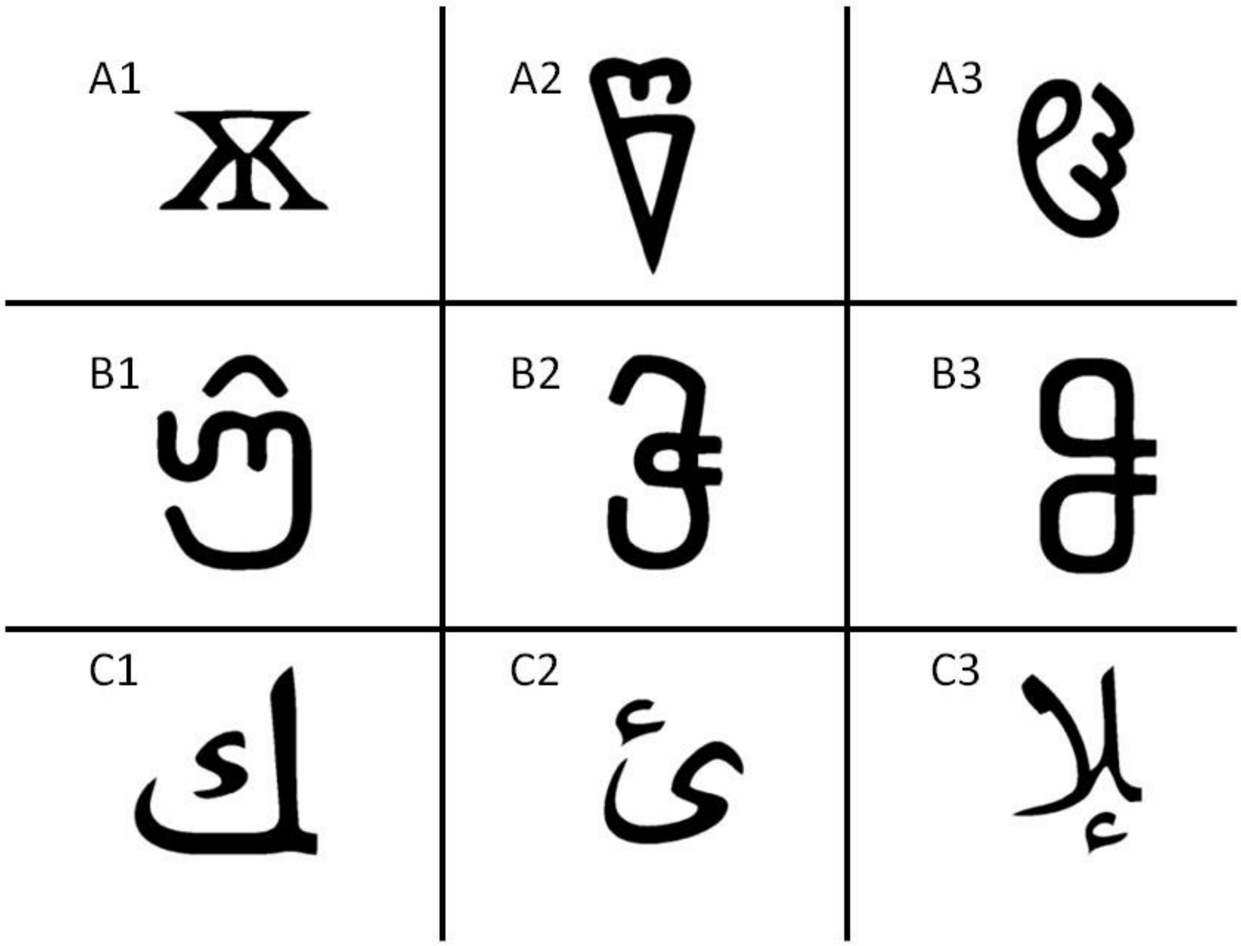

Figure 4.

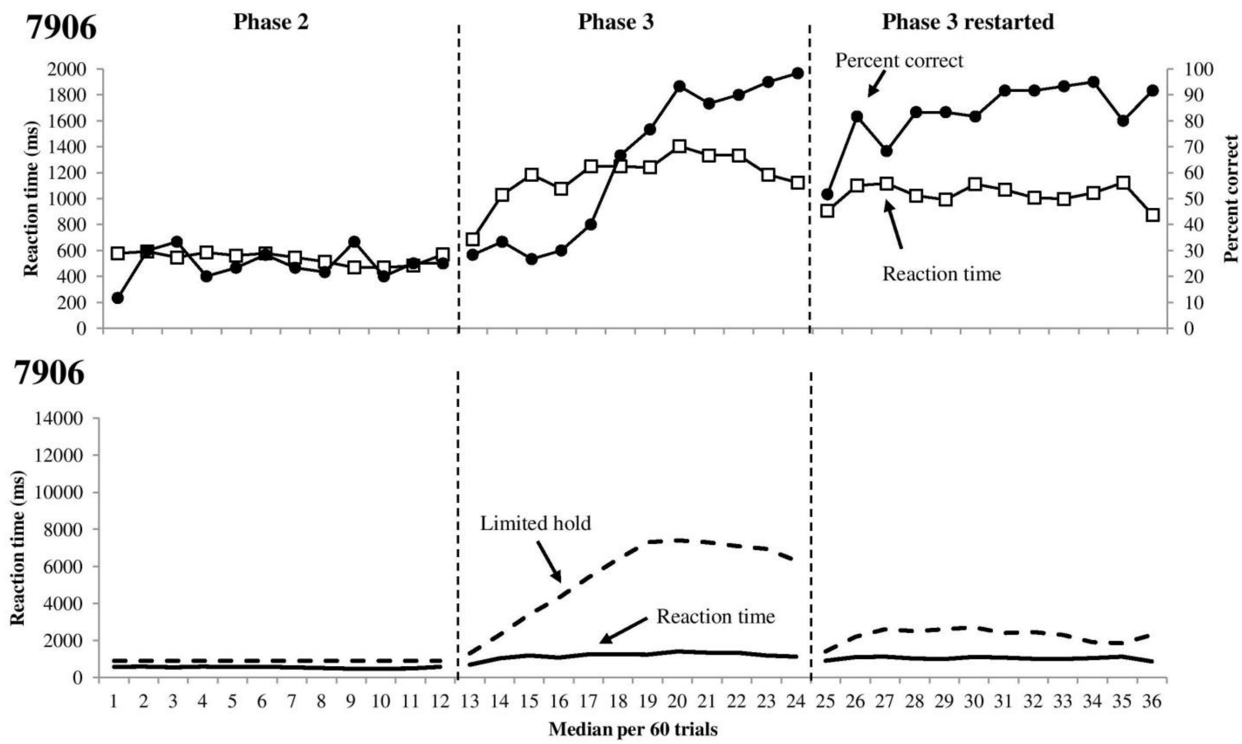

Figure 5

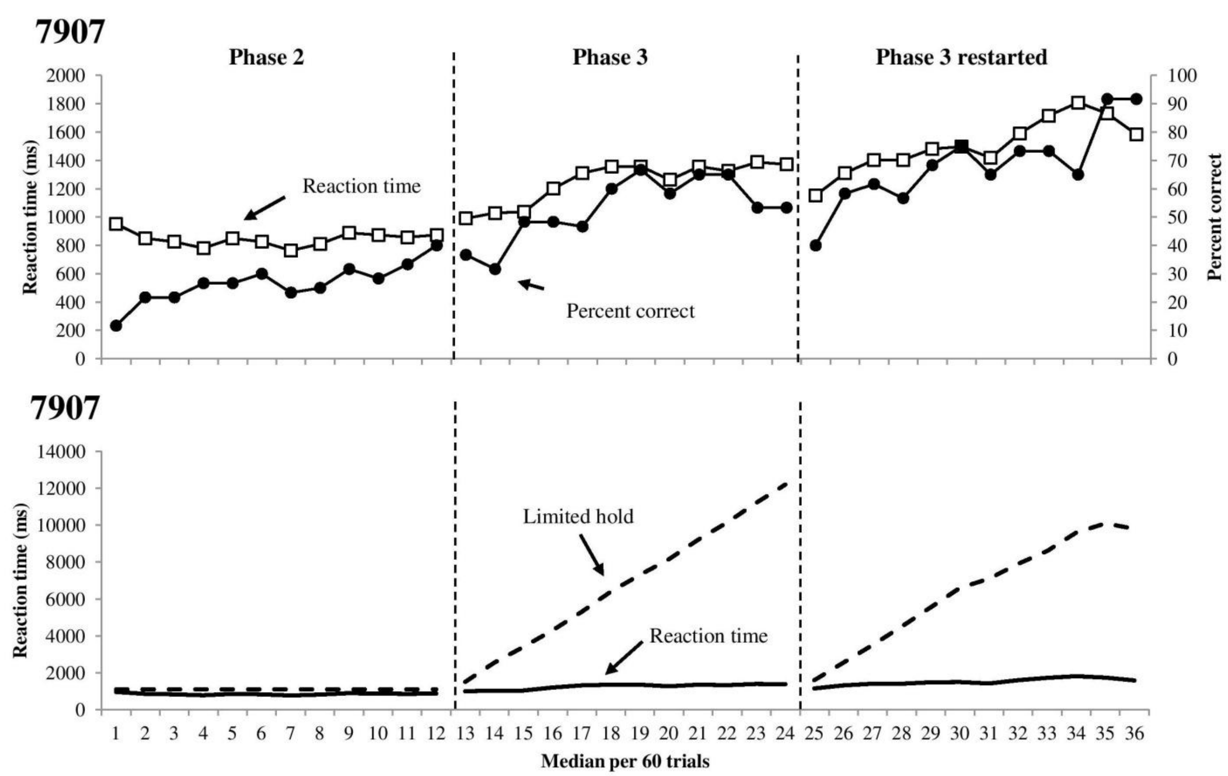

Figure 6

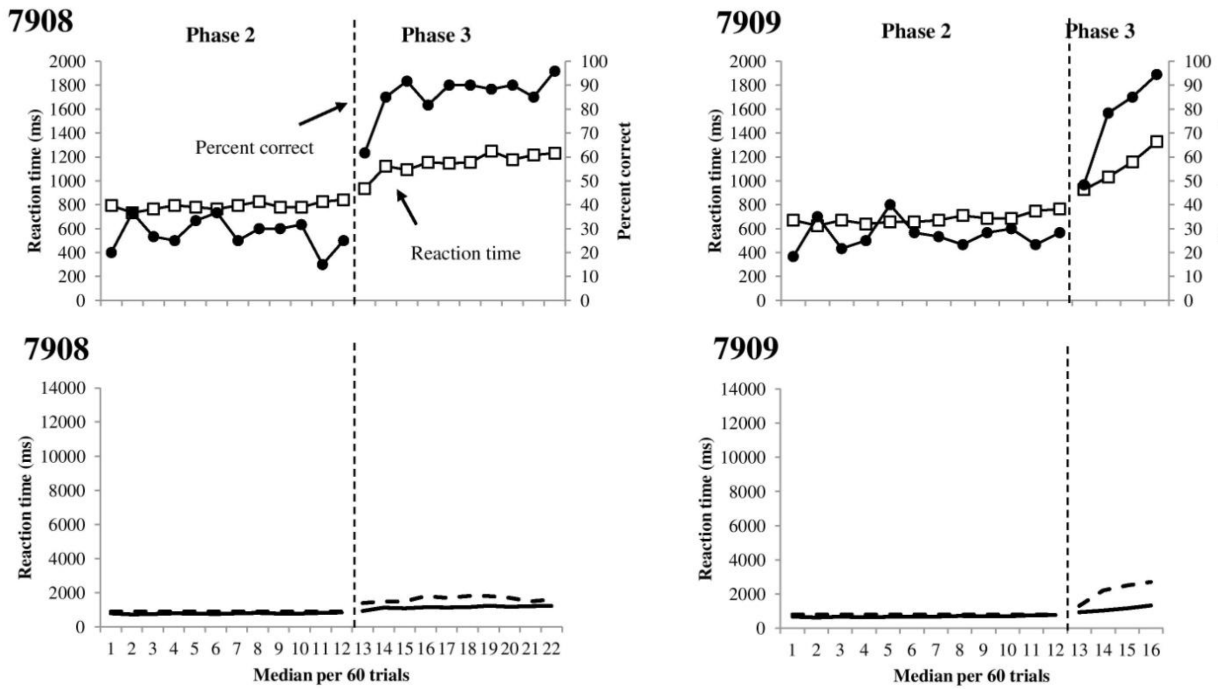

Figure 7

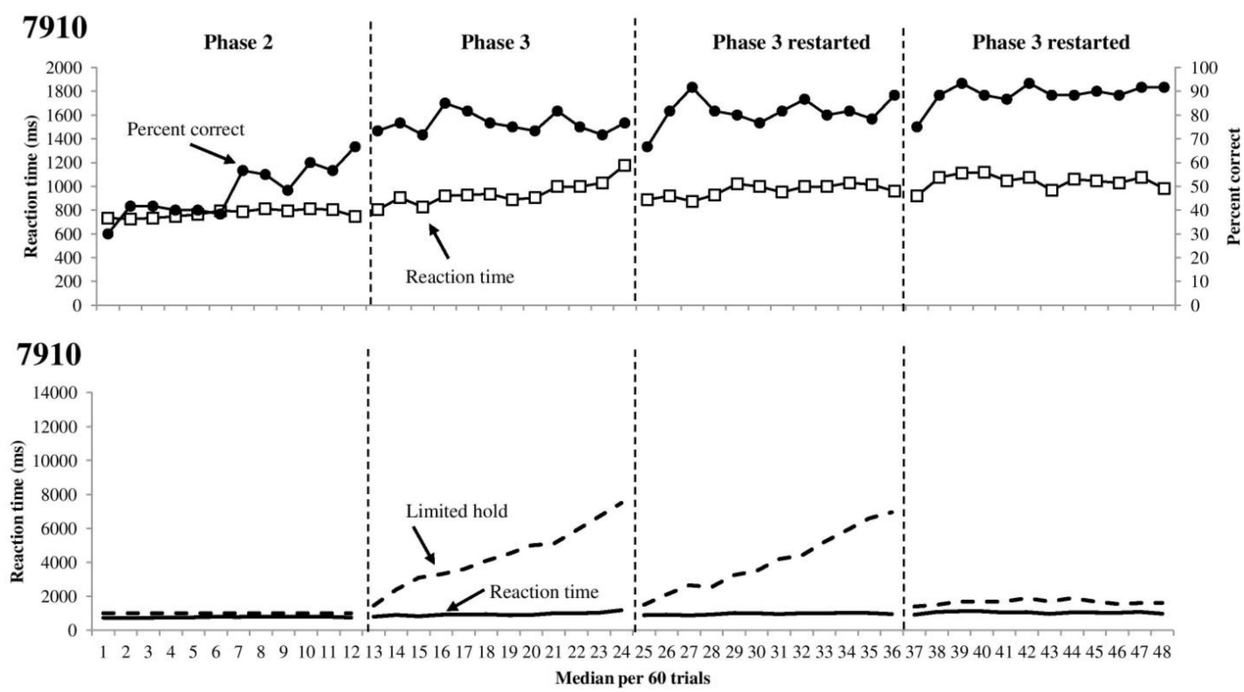

Figure 8

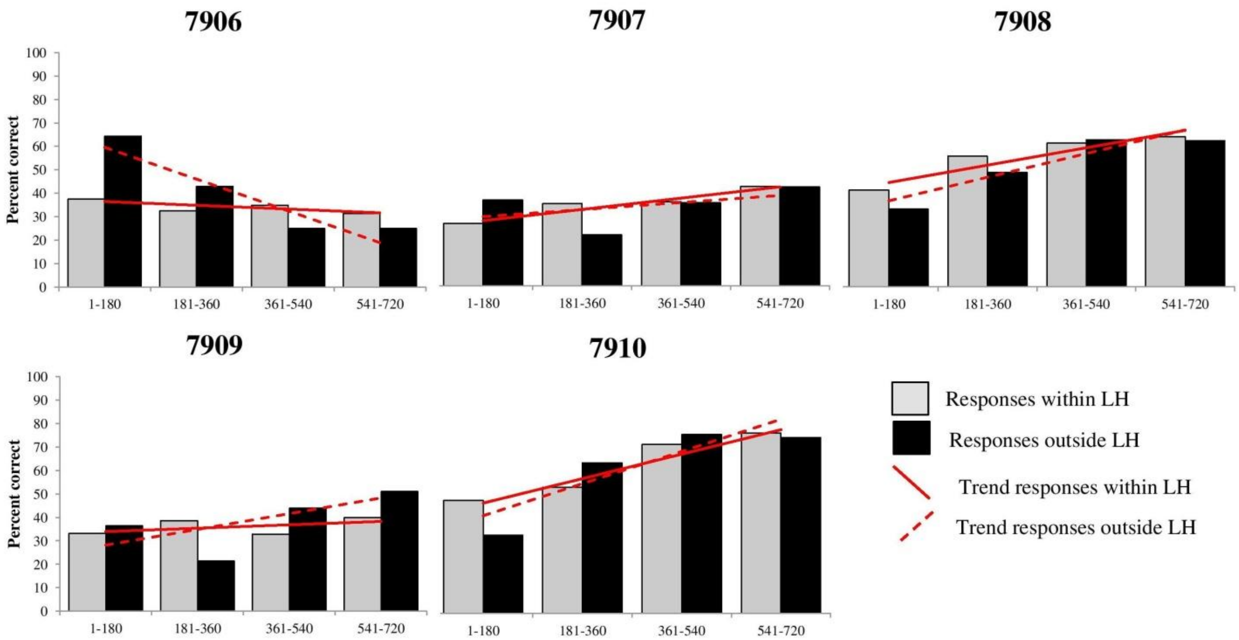

Figure 9

First phase 3

First half

	B1	B2	B3	C1	C2	C3	NR
A1	58	0	1	55	1	1	4
A2	2	39	18	2	40	17	2
A3	6	11	39	3	5	48	8

Second half

	B1	B2	B3	C1	C2	C3	NR
A1	54	0	2	53	0	0	11
A2	1	45	10	2	36	15	11
A3	2	12	39	1	6	45	15

Second phase 3

First half

	B1	B2	B3	C1	C2	C3	NR
A1	57	2	0	57	0	1	3
A2	0	38	21	0	38	17	6
A3	0	12	45	2	5	52	4

Second half

	B1	B2	B3	C1	C2	C3	NR
A1	56	0	1	58	0	0	5
A2	0	46	13	1	51	7	2
A3	1	19	38	1	7	49	5

Third phase 3

First half

	B1	B2	B3	C1	C2	C3	NR
A1	58	0	0	58	0	0	4
A2	1	47	4	0	53	2	13
A3	0	12	45	0	3	54	6

Second half

	B1	B2	B3	C1	C2	C3	NR
A1	52	0	0	53	0	1	2
A2	0	44	3	0	49	2	10
A3	0	3	45	0	4	47	9

Figure 10

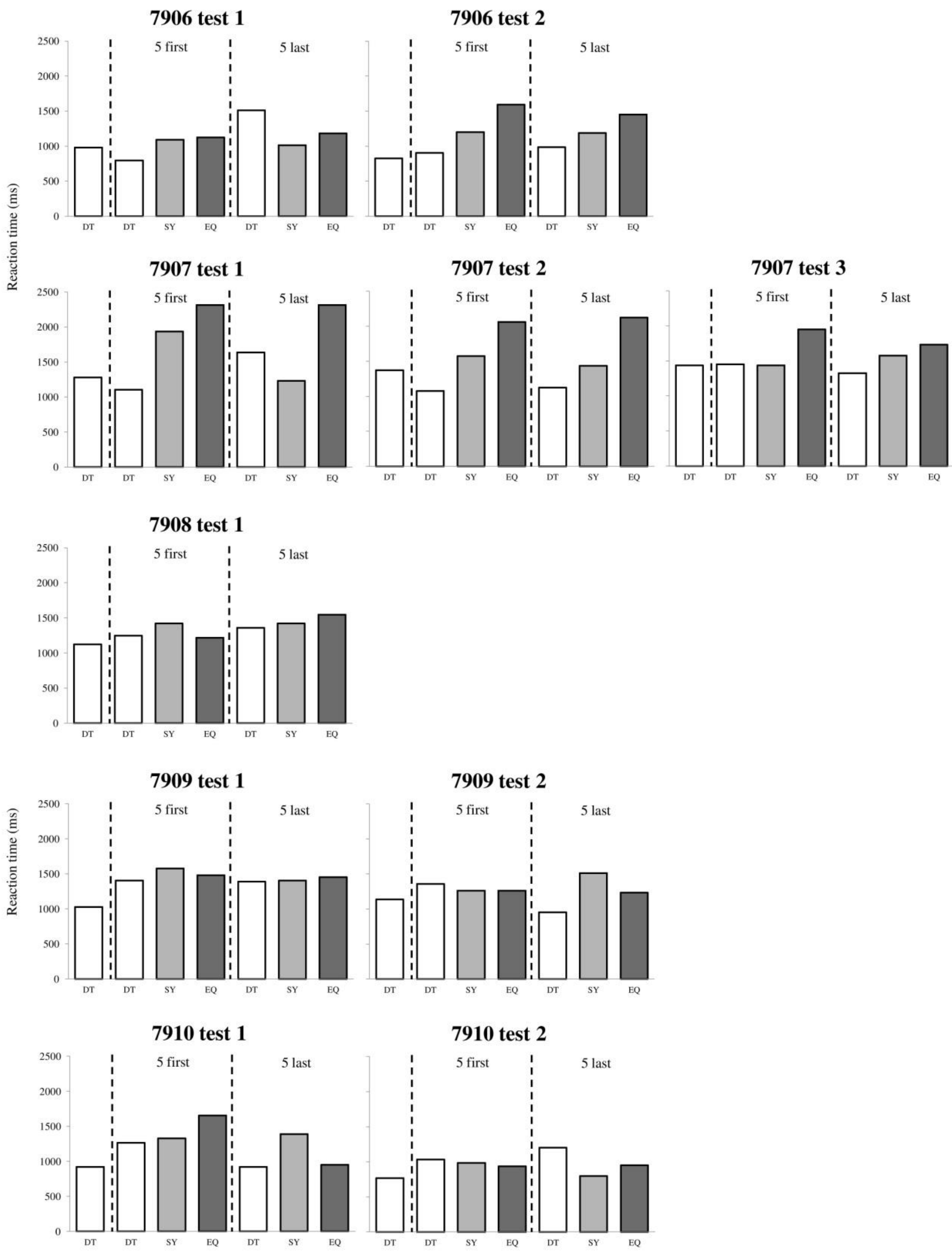
7906 test 1
7906 test 2
7907 test 1
7907 test 2
7907 test 3
7908 test 1
7909 test 1
7909 test 2
7910 test 1
7910 test 2
5 first
5 last
Reaction time (ms)
DT
SY
EQ

Figure 11.