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The use of signs to facilitate maze learning in dairy cows (*Bos taurus*).

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The dairy industry is a major contributor to the New Zealand economy, worth around \$8.6 billion in 2007 (Statistics New Zealand, 2008). Around 90 % of milk products are exported, and over the past 20 years, numbers of dairy cattle have increased by 2.6 million to a current population of around 5.26 million, making dairying one of the fastest growing industries in the country in 2008 (Statistics New Zealand, 2008). Dairy exports were projected to increase to \$11.68 billion by 2011 (Wilson & Tipples, 2008). New Zealand's productivity in dairying is largely a consequence of favourable climatic conditions (Duncan, 1933; Verkerk, 2003) and a long history of extensive investment in dairy technology.

Even early reviews of the New Zealand dairy industry described developments in dairying as “remarkable” (Duncan, 1933, p. 3). Duncan (1933) noted the impact of science on the manufacture of milk products and perhaps crucially, what he describes as the “progressive spirit” of New Zealand farmers (p. 4). He points out that New Zealand farmers not only adopted advancements made in other countries, but also applied science to make their own advancements in production, such as the design of the rotary abreast milking shed which allowed for an increase in milking numbers. Due to the importance of the dairy industry to the New Zealand economy, investment in the advancement of milking practices and technology has continued.

Meanwhile, Europe also continues to develop dairy technology. Arguably the most important recent innovation to emerge from Europe is that of Automatic Milking Systems (AMS). AMS enables unassisted milking where cows move voluntarily from a barn or field to the AMS where they are milked robotically (Lind, Ipema, de Koning, Mottram & Hermann, 2000). The AMS unit consists of a milking booth or crate and a robotic arm that swings underneath a single cow and attaches cups for milking. Automatic gates control entry to and exit from the milking crate, so the whole milking process is completed without human intervention. The main goal of this automation is the reduction and ultimate removal of human input and its associated costs from the milking process (Kuipers & Rossing, 1996). The use of AMS is in stark contrast to conventional milking which is labour intensive. Conventional milking in many countries requires that cows are moved as a herd to the dairy by the farmer to be milked at set times during the day (de Koning & Rodenburg, 2004). This herding requires that the farmer has pre-determined and cleared (i.e., opened all gates) an appropriate route from pasture to dairy. In contrast, AMS requires that cows move to the dairy without human intervention. For efficient

use of the AMS, cows must ideally arrive in a steady stream over 24 hours so that the unit is almost continually in use. Therefore, instead of cows being milked conventionally twice a day in a batch process, milking can become continuous and less laborious (Jago, Davis, Copeman & Woolford, 2006). The robotic system provides benefits to farming, including a reduction in labour costs and a more flexible lifestyle for the remaining labour force (Kuipers & Rossing, 1996). A further benefit lies in the automation itself, as the AMS unit is computer operated and stores all animal details and production figures. This allows for closer monitoring of the herd, leading to improved production and animal welfare, ultimately benefiting the dairy industry as a whole (Prescott, 1995; Schon, Artmann & Worstorff, 1992).

Usage of AMS's has increased since their development over 10 years ago (de Koning & Rodenburg, 2004). This is particularly evident in Europe, where around 2500 herds were being milked on AMS farms in 2005 (Jago & Davis, 2006). Farming in the European context typically involves small herd sizes, with cows housed indoors for the winter months or sometimes all year round (Davis, Jago, MacDonald, McGowan & Woolford, 2006; Kilgour & Dalton, 1984). Farms tend to be small, and if grazing is combined with milking, pasture is usually located nearby (Jago & Davis, 2006). Due to this style of farming, there is more potential for adoption of AMS technology in Europe than in New Zealand. Many European AMS farms plan the location of the AMS unit to be inside a barn with cow housing (Jago & Davis, 2006), which means that inevitably there are only short distances between the herd and the AMS unit. Combining the AMS with cow housing and limited (if any) pasture use means that the route to reach the AMS is likely to be constant. A further advantage is that the automatic selection of cows who are due to be milked also occurs indoors, so cows not due to be milked can be sent back to the herd via a short route. The use of small herd numbers and small farms has led to the successful implementation of AMS in Europe, however, it is not clear how automation can be successfully implemented in the New Zealand farming context.

New Zealand farming practises are very different from those in Europe. New Zealand farms typically cover large areas and herds of 300 cows or more are common (Verkerk, 2003). New Zealand dairy farms are predominantly pasture based (Duncan, 1933; Verkerk, 2003), with cows at pasture all year round (Davis et al., 2006). Therefore there is little or no reliance on indoor housing, even in winter. To ensure adequate management of pasture levels, grazed pasture

is rotated regularly with rotation lengths of up to 70-80 days. As such, cows are regularly (in some cases daily) moved to new pasture and may not experience the same path to the dairy from one section of pasture until that pasture is grazed again at the end of the rotation up to 80 days later. Therefore, unlike European farms, the path required to reach the milking shed is not constant, and is likely to vary considerably over the rotation period. Therefore, more so than in Europe, New Zealand farm design may be considered maze-like, as many different paths (i.e., farm races) connect different parts of the farm, which means that a number of sequences are required to move from pasture to reach the dairy. A further difference between farming in New Zealand and Europe is that in New Zealand, the distances between pasture and the dairy are not short. The large size of New Zealand farms often results in animals at pasture being some distance from the milking shed and they can be required to travel up to 1 km or more every milking (Jago & Davis, 2006).

As mentioned above, the selection of cows who are due to be milked occurs indoors in Europe, where cows are faced with a short distance and very few choice points to reach the AMS unit. Selecting cows who are due to be milked is more difficult in New Zealand, with cows permanently at pasture and some distance from the milking shed. On a prototypical AMS test farm (The Greenfield Project), automatic milking was adopted in conjunction with a selection unit (SU) with the aim of facilitating cow flow to and from the AMS unit. Located centrally at pasture, the SU was a circular, concreted yard area containing a number of water troughs. With no access to water at pasture, cow movement between the SU and surrounding pasture was guaranteed. Entry and exit to the SU was controlled by a combination of one-way cow-operated gates and computer-operated automatic gates that functioned to control cow flow (Davis & Jago, 2002). When cows passed through the SU, an electronic identification system scanned a pedometer or eartag and identified if the cow was due to be milked. Automatic gates allowed cows ready for milking to move into the race leading to the dairy, and allowed cows not ready for milking to move back to pasture (Jago, Bright, Copeman, Davis, Jackson, Ohnstad & Wieliczko, 2004). While the SU is used to improve cow flow between pasture and the AMS, its location can still often be some distance from the dairy. Cows are required to find the SU from pasture and discriminate appropriate stimuli that provide information as to what they have to do

from there (e.g., discriminate which gate leads to the dairy to be milked and which gate leads to a return to pasture).

Therefore, the successful use of AMS is almost entirely reliant on appropriate cow behaviour (Prescott, 1995; Prescott, Mottram & Webster, 1998a). Whether in Europe or New Zealand, cows must still learn to walk to the AMS unit, enter the milking crate and stand quietly during the milking process. Research has shown that cows can learn to be milked in an automatic system (Gygax, Neuffer, Kaufman, Hauser & Wechsler, 2008; Hagen, Lexer, Palme, Troxler & Waiblinger, 2004; Hagen, Langbein, Schmied, Lexer & Waiblinger, 2005; Hopster, Bruckmaier, Van der Werf, Korte, Macuhova, Korte-Bouws & van Reenan, 2002), and adjust their behaviour when changing from being milked conventionally to an AMS (Weiss, Helmreich, Möstl, Dzdic & Bruckmaier, 2004). It has also been shown that AMS can be combined with a fully pasture-based system, both in a European study (Ketelaar de-Lauwere, Ipema, van Ouwerkerk, Hendriks, Metz, Noordhuizen & Schouten, 1999) and on a prototypical AMS farm in New Zealand (Jago, Copeman, Bright, McLean, Ohnstad, & Woolford, 2002; Jago, Davis, Blackmore & Temple, 2006). However, there are still ongoing issues in New Zealand, with the efficiency of the system dependent on the process of cows learning to find their own way to the selection and milking units from pasture (Davis & Jago, 2002).

Problems with the AMS. European research has shown that cows show some resistance to visiting the AMS voluntarily (Kuipers & Rossing, 1996), so the need to stimulate cows to increase voluntary visits has been suggested (Wredle, Munksgaard & Spörndly, 2006). Methods of increasing voluntary visits to the AMS have involved the use of conditioning techniques that aim to develop an association between visiting the AMS and a positive event. For example, providing supplementary feed at the AMS is widely recognised as a motivating factor (Ceballos & Weary, 2002; Prescott et al., 1998a) and therefore is one method of encouraging visits (Kuipers & Rossing, 1996). Behavioural methods, whereby the learning of responses are contingent upon a subject's actions (Fantino & Logan, 1979), may also be used to train appropriate behaviour. Cows have previously been trained to approach a set place in response to auditory signals (Albright, Gordon, Black, Dietrich & Synder, 1966; Kiley-Worthington & Savage, 1978; Wierenga & Hopster, 1988; Wredle, Rushen, de Passile & Munksgaard, 2004), and the playing of music has increased visits to an AMS (Uetake, Hurnik & Johnson, 1997) as

has the playing of an auditory signal (Wredle et al., 2006). While these studies demonstrate the potential for training strategies to improve voluntary visits to the AMS, their relevance to the farming system used in New Zealand is questionable. Firstly, a majority of studies have been conducted in Europe, where the AMS unit is contained inside a barn adjacent to or part of cow housing, so the distance between cow housing and the milking unit is short and the route remains constant. Secondly, while a signal may provide an indication to start the process of moving to the AMS, it does not provide any information as to where the cows should go to reach the dairy. Therefore this type of training may not be as effective in New Zealand, where large distances between cows at pasture and the milking shed are typical.

If voluntary visits to the AMS are not achieved by cows, they have to be manually fetched from pasture, resulting in an increase in labour input (Wredle et al., 2006). European research has shown that pasture levels and distance between the pasture and the AMS unit can affect voluntary visits. For example, Ketelaar-de Lauwere, Ipema, Lokhorst, Metz, Noordhuizen, Schouten and Smits (2000) reported that longer grass at pasture resulted in fewer visits to an AMS, presumably because the high availability of grass offers positive reinforcement in that cows will remain longer at pasture. When sward height decreased, visits to the AMS increased. A similar observation has also been reported on a prototype AMS farm in New Zealand (Davis et al., 2006). European research has also investigated combining pasture access with an automatic system, leading to contradictory findings. Ketelaar-de Lauwere et al. (2000) reported that distances of up to 360 m between pasture and the dairy did not affect the number of visits to an AMS, however, Spörndly and Wredle (2004) showed that cows grazing 50 m from the milking shed visited an AMS more than cows grazing 260 m from the milking shed, which suggests that distance may be an issue, even on European farms. As previously indicated, New Zealand farms typically cover large areas. Considering that it is not known what would occur at even larger distances, it would seem that further research is relevant.

With the farming system in New Zealand, an important goal of AMS is to avoid manually moving cows from pasture to the SU or dairy (Davis et al., 2006). Training cows to make their way from the pasture to the dairy and back again is recognized as the most labour-intensive aspect of instituting an AMS (J. Jago, personal communication, 2005). In New Zealand, cows often either choose to avoid, or fail to find, the different gates that guide them from pasture,

through the selection unit and to the AMS (J. Jago, personal communication, 2005). This situation then results in cows having to be manually retrieved from pasture and driven to the dairy for milking, as occurs on conventional farms. This problem also appears to be more apparent when the appropriate pathway to the dairy involves a backwards direction (i.e., a path which initially requires that cows move away from the goal of the dairy and away from other cows that may be visible in the race to get to the selection unit) (J. Jago, personal communication, 2005). Particular farm layouts may make detour paths inevitable, so methods of helping cows select the route to reach the dairy are needed. Cows learning to find the SU and dairy from pasture is, then, an important part of AMS. To the author's knowledge, no behavioural research has addressed the issue of aiding cows to select the route to the AMS when it is combined with fully pasture based farming. Therefore, investigation into strategies that can reduce the time cows spend learning how to get to the AMS seems warranted given the contribution that the successful implementation of AMS can offer to the New Zealand dairy industry.

Kilgour (1987) suggests that it is beneficial to have some understanding of how an animal learns. The dairy cow is extensively farmed and handled worldwide, yet there is a general lack of behavioural research with this species. While their trainability has been recognised (Jago & Davis, 2006) it could be argued that the learning ability of cows has not been fully utilised in farming practice, despite suggestions that it be incorporated more in farming (Kilgour, 1981). Existing behavioural research often involves the use of small experimental numbers (i.e., one or few animals) (Soffie, Thines & Falter, 1980), a situation which may be as a result of the size and temperament of cattle, which can make training difficult and time-consuming (Jacobs, 1981; Soffie et al., 1980). Despite these constraints, it is desirable to include a behavioural investigation of cows' learning when considering the implementation of an automatic system. As indicated earlier, learning to move through an AMS requires more behaviour from cows than a conventional milking system. Cows have to discriminate different stimuli in and around the AMS unit, and learn the correct path to reach the milking shed, which can be maze-like due to the size and design of farms in New Zealand. Furthermore, specific to the New Zealand farming context, cows must learn a new route each time the grazing rotation changes and so have to change previously learned behaviour.

To address some of the issues these conditions raise, Experiment 1, which will be introduced next, involved an investigation of whether cows can learn to approach a visual discriminative stimulus in a simple simultaneous discrimination. If cows can learn to use a visual cue, there may be potential for that cue to be used as a ‘sign’ or signal to a correct path, for example, to a milking shed. This in turn has the potential to reduce the time spent learning to select a path through an AMS gate system, which, particularly in the New Zealand farming context, is an area of difficulty with regards to training cows to use such a system. The aim was to use a procedure that was as similar as possible to the situation to which it might be applied. Hence, the experiment was conducted in a cattle yard and cows had to learn to select and move through a pair of one-way gates associated with stimuli to gain access to food.

AMS also requires cows to respond rapidly to changes in the correct path, thus, Experiment 2 examined cows’ ability to change from a previously learned path to a new path to gain food. This experiment also examined whether or not the provision of a sign could help this learning. An additional expectation of cows on AMS farms is that they travel to the dairy without human assistance or the presence of the herd. Routes on New Zealand farms often involve more complex paths; therefore, it was the aim of Experiments 3 and 4 to measure the ability of cows to learn simple and complex mazes to approximate what cows must learn on farms. New Zealand’s pasture based farming system results in an environment that is constantly changing for the animals being farmed. Cows must learn one path to reach the dairy, then transfer this learning when they are faced with learning a new path the following day. Cows must also learn to discriminate automatic and cow-operated gates in one setting, i.e., at the AMS unit and yards, and transfer that learning to another setting, i.e., pasture and the SU. Therefore, for an automatic system to operate efficiently, cows must show that they can transfer learning across settings. To investigate this issue, Experiment 5 investigated the ability of cows to learn to approach a visual stimulus in one location and transfer that learning to a new setting.

Experiment 1

To learn how to use an AMS, dairy cows need to discriminate stimuli involved in order to travel to the AMS unit from pasture. Discrimination is seen when behaviour regularly occurs in the presence of a stimulus that gains access to an appetitive consequence or removes an aversive consequence, but does not occur in the presence of a stimulus that does not gain access to an appetitive consequence or gains an aversive consequence (Blackman, 1974). For example, when responses to a lit key are reinforced but responses to an unlit key are not reinforced, an animal will subsequently respond to the key when it is lit but not when it is unlit. The lit and unlit key have become discriminative stimuli and it can be said that an animals' behaviour is under stimulus control (or under the control of the key light). The accuracy with which discriminations are made has some survival importance, as different stimuli come to signal different events that an animal must adapt to (Pearce, 1987).

Discrimination learning can be investigated using two general methods: both forms of conditioning. These are classical and operant conditioning. Classical conditioning involves the pairing of a neutral stimulus with a stimulus that elicits a reflexive response (Rachlin, 1970). For example, Abramson, Armstrong, Feinman and Feinman (1988) conditioned an avoidance response in the crab by pairing a previously neutral stimulus (vibrations to the crab's shell) with an aversive stimulus (a puff of air). Shell vibration came to elicit eye withdrawal, showing that crabs had learned to avoid the puff of air by responding to the signal. Therefore, crabs had learned to respond to the vibration and not to respond to no vibration, showing discrimination. Operant conditioning involves the training of responses, whereby learning is contingent on a subject's actions (Fantino & Logan, 1979). For example, Hanggi and Ingersoll (2009) investigated scotopic vision in horses. Four horses were trained to select geometric figures (circles and triangles) under varying dim light conditions. They showed that horses could learn to correctly discriminate geometric figures in light conditions too dark for human vision, suggesting that horses have excellent vision in low light.

Within operant conditioning, procedures to train discriminations differ according to the type of responses (i.e., one or more) required. Two procedures commonly used with multiple response manipulanda are the Yes/No and Forced-choice method (Blough & Blough, 1977). The Yes/No method involves a response to one alternative being reinforced if a particular condition is

present (yes) and a response to the other being reinforced if the condition is absent (no) (Blough & Blough, 1977). This method has been used to measure hearing in ferrets (Kelly, Kavanagh & Dalton, 1986) and visual discrimination in the brushtail possum (Signal, Temple and Foster, 2001). The procedure most frequently used to teach visual discriminations is the forced-choice method (Blough & Blough, 1977). This procedure involves the presentation of two stimuli, of which responses to the alternative associated with the stimulus designated as correct are reinforced. For example, studies of colour vision often teach discriminations between two stimuli (usually one coloured and one grey) and provide access to reinforcement for responses to the coloured stimulus. Forced-choice tasks have been used to train colour versus grey discriminations in horses (Blackmore et al., 2008) and cows (Riol, Sanchez, Eguren & Gaudioso, 1989) as well as other species, e.g., manatees (Griebel & Schmid, 1996) and primates (De Valois & Jacobs, 1968).

Theory has been interested in determining how discriminations are learned and how behaviour comes under the control of various stimuli. Mackintosh (1974) suggested that discriminations can be learned successively or simultaneously. Successive discriminations involve learning to discriminate one set of stimuli at a time (i.e., respond in the presence of one stimulus but not in the presence of another), while simultaneous discrimination learning requires that subjects discriminate between stimuli when they are presented at the same time (i.e., respond to one stimulus, but respond differently to the other) (Mackintosh, 1974; Rachlin, 1970; 1976). Mackintosh describes the learning of two-choice, simultaneous and successive discriminations in terms of either response-selection or stimulus-approach. For example, a simple black/white simultaneous discrimination, in which the selection of the positive stimulus (black) is reinforced but selection of the negative stimulus (white) is not reinforced, is learned through response-selection by turning left when the stimulus configuration is black/white and right when the stimulus configuration is white/black. In a successive discrimination, the same stimuli are presented as black/black or white/white, and under response selection would be learned by turning left when both stimuli are white and right when both stimuli are black (Mackintosh, 1974). Under stimulus-approach, simultaneous discriminations are learned by approaching black and avoiding white regardless of the side presented. Presented successively, both stimuli are black, and the discrimination is learned by approaching black on the left (and not approaching black on the right), but when both are white, it is learned by approaching white on the right (and

not white on the left) (Mackintosh, 1974). Mackintosh suggests that simultaneous discriminations are learned through stimulus-approach; however, determining which process is controlling behaviour is often not definitive, as in any individual discrimination, it may be difficult to determine which process has occurred.

What cows learn when making different discriminations has not been determined. Existing studies tend to show the cows' ability to learn to avoid aversive stimuli. For example, cows learn to stay inside fenced areas to avoid the aversive experience of an electric shock (Lee, Prayaga, Reed & Henshall, 2007), will learn to avoid people who have treated them aversively (Munksgaard, dePassille, Rushen, Herskin & Kristensen, 2001), and will learn to avoid the location of an aversive stimulus (i.e., noise) (Arnold, Ng, Jongman & Hemsworth, 2008). Blackmore, Temple, Jago and Brown (unpublished) conducted a preliminary study to determine what aspects of stimuli cows attend to (i.e., colour or shape). They presented a simultaneous discrimination in which a red cross on a grey background (positive stimulus) was paired with a yellow triangle on a grey background (negative stimulus). Different combinations of these stimuli (i.e., red cross vs. red triangle, red cross vs. yellow cross, yellow cross vs. yellow triangle, red triangle vs. yellow triangle) were presented to determine which aspect of the stimuli were being discriminated. They found that cows were discriminating on the basis of colour rather than shape, as accuracy decreased during tests where the colours were the same but the shapes were different (i.e., red cross and red triangle were chosen equally). They also showed that when the red cross was paired with a plain grey background, correct responding decreased to chance levels despite the previous training to go towards the red cross. When the yellow triangle was paired with a grey background, responding shifted towards 100 % grey, which suggested that the discrimination was learned through stimulus-approach, in that cows learned not to approach the negative stimulus rather than to approach the positive stimulus. de Passille, Rushen, Ladewig and Petherick (1996), Munksgaard, de Passille, Rushen, Thodberg and Jensen (1997) and Taylor and Davis (1998) reported their findings in terms of approach and non-approach of stimuli. In their studies, cows approached an S+ handler and avoided an S- handler on the basis of food reinforcement (Taylor & Davis, 1998) and approached an S+ handler and avoided an S- handler based on gentle and aversive handling (de Passille et al., 1996; Munksgaard et al., 1997). The results of these studies suggest that cows may learn both to approach and avoid stimuli.

With human intervention reduced on AMS farms, it may be argued that cows must learn to discriminate and approach rather than avoid stimuli in order to learn to use the automatic system successfully. It has been shown that cows can learn to approach a set place in response to auditory signals (Albright et al., 1966; Kiley-Worthington & Savage, 1978; Wierenga & Hopster, 1988; Uetake et al., 1997; Wredle et al., 2004; Wredle et al., 2006), but whether they can learn to approach a set place in response to visual stimuli has not been fully explored. However, before presenting an animal with a visual discrimination, physiological knowledge of their visual system is necessary to determine if they are physiologically capable of perceiving the stimuli presented to them.

Cattle have large eyes and a wide field of vision (Grandin, 1997). Both rods and cones are present in the retina (Albright & Arave, 1997; Gilbert & Arave, 1986; Jacobs, Deegan & Neitz, 1998; Phillips & Lomas, 2001). The presence of two cones in the retina, which are required for any degree of colour vision, confirms the physiological potential for colour perception. Electroretinogram readings have shown cones to peak at 554 nanometers (nm), corresponding to a medium-long wavelength receptor and at 455 nm, corresponding to a short wavelength receptor (Jacobs et al., 1998). These findings suggest that cows have a dichromatic visual system, as has been reported for other ungulates, e.g., horses (Blackmore et al., 2008; Sandmann, Boycott & Peichl, 1996); pigs (Hebel & Sambras, 1976; Neitz & Jacobs, 1989); sheep (Alexander & Stevens, 1979; Jacobs et al., 1998) and goats (Jacobs et al., 1998).

In addition to anatomical evidence, confirmation that cattle can discriminate colours through behavioural studies are also necessary (Kelber, Vorobyev & Osorio, 2003; Macuda, 2000). Existing behavioural research supports the histology. Research has shown that yellow can be discriminated from shades of grey, along with other long wavelength colours such as red and orange (i.e., Dabrowska, Harmata, Lenkiewicz, Schiffer & Wojtusiak, 1981; Phillips & Lomas, 2001; Riol et al., 1989; Soffie et al., 1980; Thines & Soffie, 1977). These findings have been used as a basis for further research; Munksgaard, de Passille, Rushen and Ladewig (1999) used yellow and red coloured overalls to show that cattle can discriminate between people, and Prescott (1995) showed that cows could discriminate between yellow and red buckets. On the basis of these studies, it seems appropriate to consider colour as one dimension of visual stimuli that may be presented to cattle.

Research on the ability of cattle to learn to discriminate between shapes and objects is fairly limited (Baldwin, 1981; Entsu, Dohi & Yamada, 1992). It has been previously reported that cattle can learn simple discriminations, such as discriminating between buckets of differing size (Schaeffer & Sikes, 1971) as well as differing colour (Schaeffer & Sikes, 1971; Wieckert, Johnson, Offord & Barr, 1966). Baldwin (1981) showed that sheep and cattle could learn more complex discriminations. He reported that sheep and calves were able to discriminate between pairs of shapes (circles, squares, triangles, crosses, bars and T bars) and different orientations of the same shapes. Entsu et al. (1992), in measuring visual acuity, found that cattle could learn to discriminate Landolt rings of differing sizes (ranging from 60 mm to 270 mm), and Rehkamper and Gorlach (1997) reported that bulls learned to discriminate disks with at least a four-time size difference between them. It has also been shown that cattle can discriminate familiar herd members (Hagen & Broom, 2003), different handlers (Taylor & Davis, 1998), and handlers on the basis of facial features and height (Rybarczyk, Koba, Rushen, Tanida & de Passille, 2003).

Pollard, Baldock and Lewis (1971) suggested that the extent to which an animal may use visual stimuli to learn discriminations may be dependent on how reliant that animal is on their visual system for survival. As foraging animals, cattle, as well as other ungulates, have to forage efficiently, and so rely on the accurate visual identification of diverse foraging areas (Howery, Bailey, Ruyle & Renken, 2000). Sheep can learn to associate visual cues with food (Edwards, Newman, Parsons & Krebs, 1997), and a handful of studies have shown that cattle can learn to associate the location of food with a visual cue. Kidunda and Rittenhouse (1992) showed that cattle learned to locate corn and barley when their position was cued with flags that differed in colour (yellow or green) and height (short or tall). A tall yellow flag was initially paired with corn (tall/yellow/corn), and a short green flag was paired with barley (short/green/barley) before the flags and foods were switched (i.e., tall/green/corn and short/yellow/barley). Cows learned the initial configuration of corn/tall yellow flag, and also learned to switch responding to the configuration of corn/tall green flag, responding at over 90 % correct on both tasks.

Howery et al. (2000) paired traffic cones and traffic barricades with high and low quality foods. They compared the learning of a group of animals that were presented with the visual cue with a group of animals that were not presented with the visual cue. They showed that cued animals were more efficient at locating food than un-cued animals. In a similar study, Renken, Howery, Ruyle and Enns (2008) also paired food with a traffic cone and compared the ability of

heifers trained with the cue and heifers not trained with the cue to correctly locate food. Trained heifers were better at locating high quality pasture, showing that they were responding to the cue provided. The above studies show that cattle can learn simple and complex discriminations, and will select different stimuli on the basis of visual cues when they are provided. Therefore, training cows to attend to visual cues seems a plausible starting point to investigate whether visual stimuli may be usefully applied to new technology such as AMS.

Once a discrimination is learned, it may be important that behaviour can transfer, or generalise to other settings. Cooper, Heron and Heward (1987) point out that several terms are used when defining generalisation. Cooper et al. define behaviour generality as “behavior changes that occur in nontraining conditions” (p. 555). They also point out that stimulus generalisation and transfer of training are terms used to define generalisation that occurs over settings, people and conditions. Stimulus generalisation occurs where responses to one stimulus are also emitted in the presence of another, similar stimulus (Mazur, 1994). For example, Guttman and Kalish (1956) demonstrated stimulus generalisation when they showed that four pigeons, each assigned a coloured light, learned to peck that light, and generalised responding by continuing to peck in the presence of ten other coloured lights that varied either side of the original trained wavelength. A generalisation gradient showed that responding steadily decreased as the coloured lights became increasingly different from the original. This showed that not only was behaviour under control of the original light, but that other coloured lights also came to control behaviour, although the degree to which they did this weakened in a systematic fashion. To demonstrate generalisation across settings, Van Den Pol, Iwata, Ivancic, Page, Neef, and Whitley (1981) taught three adults with an intellectual disability appropriate behaviour needed to successfully order a meal in a fast food restaurant. Their subjects first underwent training in a classroom setting before generalisation probes were used to measure whether the behaviour learned in the classroom had generalised to real restaurant settings. They showed that the behaviours learned in the classroom setting were transferred to McDonald’s restaurants, and that subjects also generalised learning to other restaurant chains (e.g., Burger King).

Animal trainers usually expect that behaviours learned in one setting will also be displayed in other locations, therefore training is generally undertaken in those different locations to achieve this (Burch & Bailey, 1999). Farmed animals commonly experience transportation between locations (i.e., other farms) in New Zealand. A change in location means

that animals are often presented with new stimuli, such as new housing layouts (if in Europe), new milking shed layouts and new animals and people (Wechsler & Lea, 2007). There is an expectation that animals will perform appropriate behaviours in a new setting, regardless of whether any elements common to the original setting exist in the new location. Usually no further training is given when animals are faced with new situations, as extended training is generally associated with increased labour costs and time. Even farmers who may be regarded as ‘good’ trainers will spend only a minimal amount of time training new animals (i.e., heifers at their first milking). Therefore, farmers adopt a kind of ‘train and hope’ strategy, which, as outlined by Stokes and Baer (1977) involves a hope that a transfer of training occurs without any active attempts to achieve it through additional efforts.

Research on farm animals and generalisation has usually focussed on the human-animal interaction, with aims of improving welfare and productivity (Breuer, Hemsworth, Barnett, Matthews & Coleman, 2000; Hemsworth, Coleman, Barnett, Borg & Dowling, 2002). For example, it has been shown that for pigs, their experiences with one handler generalise to other handlers (Hemsworth, Coleman, Cox & Barnett, 1994), as has also been shown in domestic chicks (Jones, 1994). That animals can learn to adapt behaviour is advantageous, especially when new situations are involved (Wechsler & Lea, 2007). Therefore, whether or not dairy cows can learn to transfer what has been learned in one setting (i.e., a conventional milking system) to a new setting seems particularly relevant to AMS.

Whether cattle can transfer learning across settings is not clear. A handful of studies have investigated generalisation with mixed results. de Passille et al. (1996) investigated whether calves could discriminate between different people based on handling and transfer this learning to another location. Three different handlers treated calves either positively, aversively or in a neutral manner before calves were tested by measuring time to approach each handler and duration of contact. Some initial generalisation was shown when calves avoided all three handlers, but with further testing calves consistently approached the positive handler but avoided the aversive handler in the first location. However, they reported no differences in approach to or avoidance of any handler when calves were re-tested with the same handlers in a different location, suggesting that transfer of learning across locations had not occurred.

In a similar experiment, Munksgaard et al. (1997) showed that cows did learn to discriminate between an aversive and gentle handler both in a home area and a treatment area.

Cows approached the aversive handler less in both areas, indicating that learning had generalised from one place to another. Rushen, Munksgaard, de Passille, Jensen and Thodberg (1998) used a similar procedure and found that cows showed some generalisation of learning about gentle and aversive handlers in two different locations, although they cautioned forming firm conclusions due to individual variation among animals. In a later study, Wredle et al. (2004) trained cattle to approach a feed source when it was signalled by an auditory stimulus, but failed to achieve generalisation of this training to a new location. Similarly, Wredle et al. (2006) trained cows to approach an AMS in response to an auditory signal in one location (a barn) and also failed to find generalisation of this behaviour when cows were required to respond to the signal when at pasture.

Most recently, Renken et al. (2008) investigated whether heifers could learn to associate a visual cue (an orange traffic cone) with food in a training pen and then generalise this learning to a pasture location. All training was initially conducted in the training area, where heifers learned to approach the orange cone to receive food. Heifers were then moved to a pasture location and tested on whether they could still approach the cue in that location. Performance of these heifers was compared to heifers who had received no training. They showed that the trained heifers also approached the visual cue when at pasture, showing that heifers had generalised this behaviour. An ability to generalise seems particularly relevant to AMS technology. Travelling to the milking shed by different routes in an AMS farm is very different to what cows experience on conventional farms. Whether cows can generalise learning how to select the correct path to reach the dairy when the path is regularly changing, is particularly relevant to AMS.

It was one aim of the current experiment to measure whether cows could learn to approach a location in a cattle yard when that location was signalled by a visual stimulus. Also of interest was whether cows would learn to approach the positive stimulus or avoid the negative stimulus, as this has implications for how signs might be used in an AMS. The operant chamber serves as an appropriate apparatus with smaller species, and has been adapted for use with cattle (e.g., Matthews & Temple, 1979). However, an experimental aim here was to use experimental conditions that were as close as possible to that which cows experience on-farm while still maintaining some control over the various variables. Cows in New Zealand are familiar with yard areas, and spend most of their time predominantly outdoors. Therefore, a yard area in which

stimuli could be presented seemed an appropriate apparatus. Cows must also learn to use a variety of gates (both cow-operated and automatic) on an AMS farm, so stimuli were presented on one-way gates that are typically used on AMS farms to control cow traffic by allowing flow in only one direction.

The current experiment used a two-alternative, forced-choice method to present yellow and grey stimuli in a simultaneous discrimination. Based on previous research, yellow was chosen as the positive stimulus (S+), and was presented opposite grey as the negative stimulus (S-). Stimuli were presented on one-way cow-operated gates that once pushed through, did not allow any movement back through the gates. Cows approached a pair of gates with the yellow stimulus and pushed through these to gain access to food. If the pair of gates with the grey stimulus were pushed through no food was provided. A criterion of 80 % correct over three consecutive sessions was used for training, discrimination and test sessions, which exceeds the 75 % correct that is recommended for a two-choice discrimination task (Levine & Shefner, 1991). Discrimination sessions were used to train cows to select gates with the positive stimulus. A further aim was to then assess whether either the yellow or grey stimulus, or both stimuli, were controlling behaviour. Rachlin (1970) suggested that varying positive or negative stimuli is one way of determining which of these stimuli are controlling behaviour. To address this, test sessions were presented upon the completion of discrimination sessions. The final aim was to determine if, once the discrimination was learned, the animals transferred that learning to another context. A transfer session was conducted to measure whether or not cows transferred learning about the positive stimulus to a new location.

Method

Subjects

Four experimentally naïve Friesian (0315, 6902 and 7841) and Friesian-cross (4840) dairy cows participated in the experiment. Cows were approximately 3 years old at the start of the experiment. All animals, with the exception of 6902, had come from a farm operating an automatic milking system (AMS) and therefore had some prior experience of pushing through gates at that farm. Cows were housed in a stand-off area, 24 m by 23 m that had a base of about 300 mm dirt and sawdust. The cows were walked to a paddock after each session where they had access to their daily ration of grass for about 3-4 hours. They were walked back to the stand-off area late afternoon and stayed there overnight. Cows had access to water in all areas. Over the weekend period when animals were not being used for research, they were housed in a paddock with free access to grass and water.

Apparatus

Training and discrimination sessions. Modified animal holding yards served as the apparatus for training and discrimination sessions. The yard had a concrete base and five-rail pipe fencing (see Figure 2), 1.25 m high, enclosed the whole area. On one side of the yard were two adjacent holding pens (termed here Runs 1 and 2) that measured 13.5 m long by 3 m wide and extended the length of the yard area. Figure 1 shows the layout of the runs used. Two pairs of gates (similar to those used on the AMS farm the animals had come from) were fabricated and welded to the existing yard fencing approximately 10 m along each run. The gates (0.55 m wide by 0.65 m high) could be pushed through one-way and enabled the cow to enter from the run into a feeding area 1.5 m wide by 3.5 m long (as illustrated in the right-hand plate of Figure 3). Once pushed through, the gates allowed entry to the feeding area but prevented cows from moving backwards into the run. Around 5.5-8 N force was required to push the gates open, and it was observed that cows generally approached the one-way gates with their heads low and pushed through them with their head and/or shoulders. Figure 2 shows the length of Run 1 and stimuli presentation at the end.

Stimuli consisted of four wooden boards each measuring 0.3 m by 0.3 m. Two of the boards were primed with white paint and then painted with grey paint (similar to Resene Battleship Grey™) until the grain of the wood was no longer visible. The other two boards were already painted grey from a previous experiment, so two coats of white paint were applied over the grey, followed by two coats of yellow (similar to Resene Formica Spectrum Yellow™). The approximate brightness of the stimuli under natural daylight conditions was measured using a Minolta Chroma Meter CS-100. Five readings were averaged to obtain coordinates for luminance (brightness), hue (perceived dominant wavelength) and chroma (saturation). Measurements obtained for the grey stimuli were as follows: 130.4 (brightness), 0.3122 (hue) and 0.3406 (chroma), and measurements for the yellow stimuli were: 595.6 (luminance), 0.469 (hue) and 0.4764 (chroma). Hooks (8 cm long by 3.5 cm wide) were attached to the backs of the boards so they could be hung on to one of each pair of one-way gates.

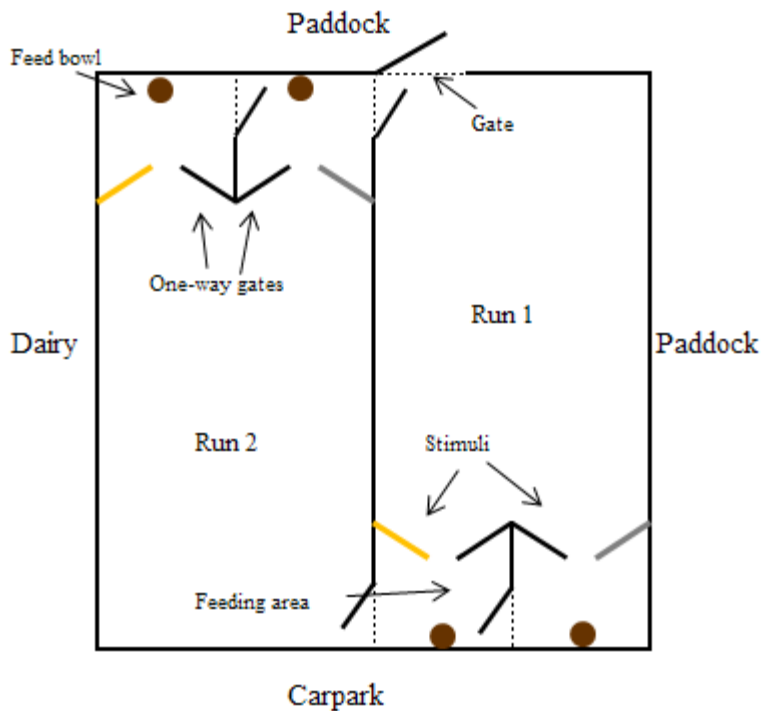


Figure 1. Layout of the yard area used.



Figure 2. Run 1 with each pair of gates (left plate) and a closer view of the stimuli and gates with feed areas and feed bowls beyond (right plate).

The feed areas behind the one-way gates contained wooden trays that were 0.5 m wide by 0.32 m long and were positioned 0.73 m from the ground. Each tray held a plastic feed bowl 0.23 m diameter and 0.115 m deep that was used for reinforcer delivery. The trays were attached to metal brackets that were hung from the yard fencing, as illustrated in the left-hand plate of Figure 3. Rubber matting, commonly used as non-slip flooring in milking sheds, was placed at points where cows had to make repetitive turns so that hooves could be protected from being damaged by the concrete. Other materials used included a Casio digital stopwatch to record trial duration and data sheets to document trial duration and selections made.

Transfer session. A transfer session was conducted in the stand-off area (24 m by 23 m) adjacent to the test yards. The stand-off was divided using electric fence tape (not electrified during the course of the trials) to reduce the area and create a holding pen where non-participating cows waited while trials were in progress. Four feed bowls and brackets were hung from the yard fencing and faced into the stand-off area. The feed bowls were placed at the end of four short runs, approximately 3 m long by 1.5 m wide, which were formed with electric fence tape (not electrified for these trials). A plastic container was placed behind each feed bowl and held a small portion of food to control for the possibility that cows were responding with the aid of olfactory cues. Figure 4 shows a plan of the layout used.



Figure 3. Feed bowl and tray (left plate), and one-way gates with feed area beyond (right plate).

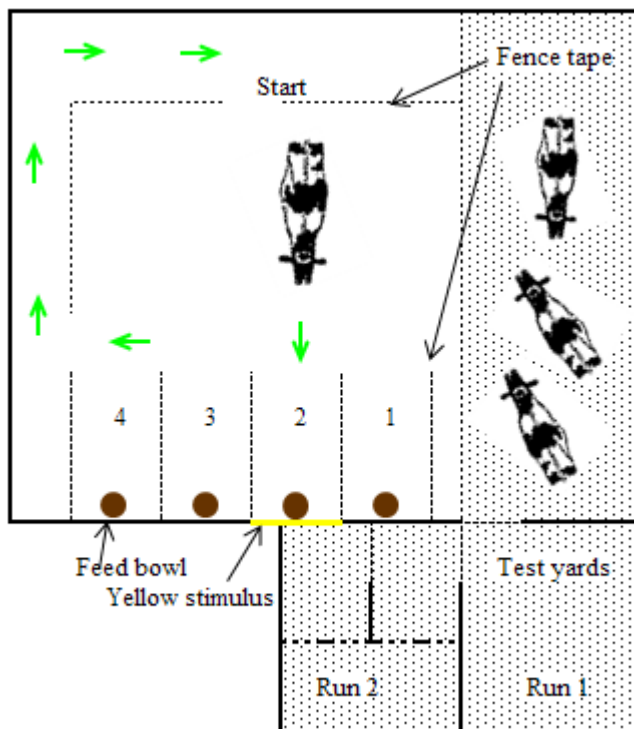


Figure 4. Layout of the stand-off area used for the transfer session.

General Procedure

The food that was made available to cows on the completion of every correct trial was prepared daily and consisted of a mixture of barley and chaff at a ratio of two measures of barley to one measure of chaff (one measure=900ml). The barley and chaff was mixed with between 250-500 ml of watered down molasses. About 125 ml of the mixture was placed in the food bowl as reinforcement. A plastic container was placed behind each feed bowl and held a small portion of food to control for the possibility that discriminations were being made with the aid of olfactory cues. Therefore with food placed at all choice points, correct choices could not be made on the basis of smell.

Sessions were conducted by two experimenters at 8.30 am Monday to Friday. Cows were separated into two pairs, with one pair taking part in the experiment on alternate days while the other pair took part on the days in between (i.e., one pair was used on three days one week while the other pair was used on two days and vice versa for the following week). One session per cow (maximum of two sessions) were conducted each day. The stand-off area was adjacent to the test yards, so all cows remained in that area while an individual cow participated in the experiment. Therefore, all cows were visible to each other whether in the test area or in the stand-off. Before every session, the pair due to take part was separated from the other pair with electrified fence tape to make it easier to draft individual cows into the test area before the session began. Typical session duration was around 45 min, with a minimum session length of around 30 min and a maximum of 60 min.

A two-choice, simultaneous discrimination was presented in which the pair of gates marked with the yellow stimulus always signalled that food was available (S+), and the pair of gates marked with the grey stimulus always signalled that no food was available (S-). To start a session, a cow was released from the paddock into Run 1 (see Figure 5 for an example of two trials). Timing of this first trial began when the cow moved from the stand-off into the test area and her shoulder had passed a marker point 1.5 m from the yard perimeter. Timing ended when the cow's shoulder pushed through a pair of gates, which was the response required. An experimenter waited at the paddock end of the yard (so as to not influence the choice) until a selection had been made. Selection was always immediate; therefore, trial duration consisted only of the time taken to walk down a run. On all correct trials, cows were given about 30 s to eat food from the

feed bowl. During this time, stimuli were changed if a change in side was required for the next trial in Run 1. On incorrect trials, no food was available, but cows remained in the feed area for approximately 30 s to 1 min and the next trial for Run 1 was set up. After the stimuli were changed, a cow was released into Run 2 for the next trial.

As soon as cows had exited the feed area from the previous trial (i.e., they were walking down the next run) food was replenished (on correct trials) and any food that was visible on the top or sides of the feed bowls was brushed away to remove the possibility that discriminations were being made on that basis. Food was not replaced on incorrect trials, but the location of the feed bowl containing food was changed if a change in side was required for the following trial. Timing of all subsequent trials began when a cow's shoulder passed a release point (about 1.5 m from the yard perimeter) after exiting the feed area. Timing stopped when her shoulder passed through a pair of gates at the end of the next run. After cows were habituated to the test area, four conditions were presented, these were: training, discrimination sessions, test sessions and one transfer session per cow.

Habituation to the test area. All cows initially spent 15 min a day for five days moving around the test area so they could become familiar with being handled in that location. Food was placed in four feed bowls that were positioned randomly within the yard area to establish that food was available. No stimuli were present during this training. All cows except one (6902) had previous familiarity with operating one-way gates, however, all cows still showed some initial reluctance to push through the gates, so some preliminary gate training was required.

Training session 1. One yellow stimulus and one grey stimulus were always present on each pair of gates for all training sessions. During Training 1, the pair of S+ gates was tied open so that cows could walk straight through to the feed area beyond to obtain food. The pair of S- gates remained closed throughout training, although they could be pushed through if chosen. Which of the pairs of gates the yellow or grey stimuli were presented on was alternated left and right according to a computer-generated quasi-random series based on Gellerman (1933), with no more than three consecutive presentations on one side. Food was always available behind the pair of S+ gates and no food was ever available behind the pair of S- gates. Sessions consisted of 30 trials, with a

criterion of two consecutive sessions above 80 % correct. Trial procedure was the same as outlined above.

Training session 2. Training 2 was the same as Training 1; with the exception that the pair of S+ gates was tied open approximately 60 degrees clockwise from the closed position. With this angle reduction the gates were still open, but brushed a cow's flanks as she passed through them. The criterion for progressing to the next stage of training was the same as for Training 1; however, session length was extended to 40 trials. One cow (4840) completed one extra day at this training condition as she was mistakenly held back from progressing despite previously reaching the criterion. Cow 7841 completed three extra days to correct a right side bias. The procedure to correct the side bias involved presenting S+ on the left pair of gates and tying them open. This procedure was used over seven trials within one session. Two following sessions were then conducted to increase accuracy back to the 80 % criterion.

Training session 3. Training 3 was the same as Training 2; with the exception that the pair of S+ gates was tied open approximately 30 degrees. Cow 6902, who had no previous gate pushing experience, continued to avoid pushing through the gates despite them being partially open, therefore she completed three more days of this training. Cow 7841 also completed further sessions as she took longer to reach the 80 % criterion for progressing to the discrimination sessions.

Discrimination sessions. Discrimination sessions consisted of the same two-choice simultaneous discrimination presented in training; however, both pairs of gates were left closed in all sessions. Which pair of gates (the left or right pair) the yellow and grey stimuli were presented on was randomly determined as mentioned above. Choosing the pair of S+ gates was considered a correct choice and was always followed by access to food, while choosing the pair of S- gates was considered an incorrect choice and always ended the trial without reinforcement. Sessions consisted of 50 trials, with an initial criterion of 85 % correct responding over five consecutive sessions. The criterion was later lowered to 80 % correct over three consecutive sessions, as although one cow (0315) was able to achieve 85 % correct, the remaining cows did not reach this criterion.

Test sessions. Once the discrimination session criterion of 80 % over three consecutive sessions had been reached, test sessions were conducted. A test session involved ten test trials that were interspersed amongst the middle 30 of 50 discrimination

trials (as described above). No test trials appeared in the first or last 10 trials of a test session. Food was placed in feed bowls behind both options for every test trial.

A test trial involved the presentation of a single yellow or grey stimulus on one pair of gates, with no stimulus present on the other pair of gates (i.e., one pair of gates was unmarked). In yellow only trials in yellow test sessions, S+ was presented on one pair of gates, and no stimulus was present on the other gate. In grey only trials in grey test sessions, only S- was presented. Which pair of gates (left or right) the stimuli were presented on was randomly determined as described above. Yellow and grey test sessions were alternated, so after a yellow test session was completed; a grey test session followed. Table 1 shows the total number of sessions completed by all cows.

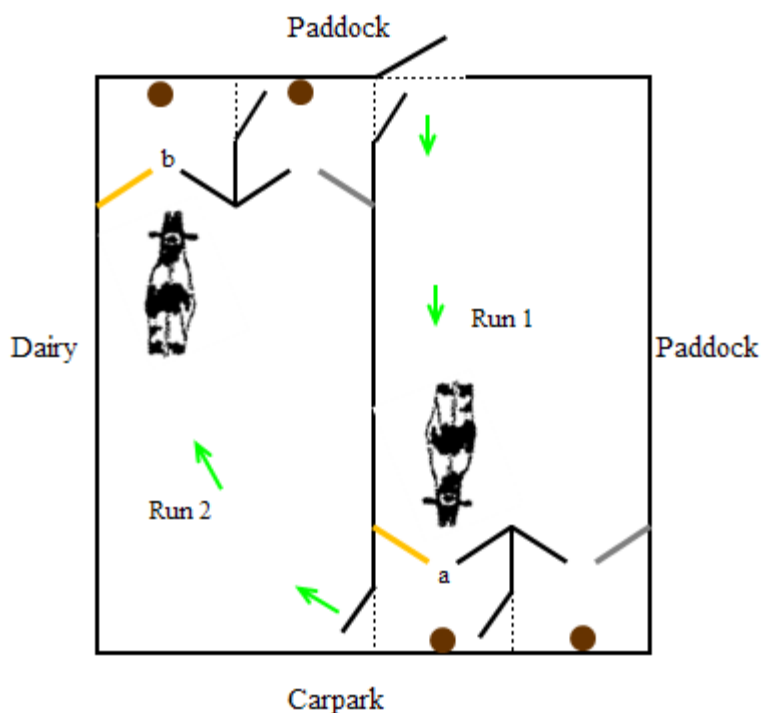


Figure 5. Trial a (right) the cow enters Run 1 from the paddock and selects the pair of S+ gates at point a. Trial b (left) the cow is released into Run 2 and approaches the next pair of gates at point b. NB: only one cow at a time was used.

An additional criterion was also in effect within a test session. The additional criterion was that if more than two errors were made in the first 10 trials of a test session (criterion = 8/10 correct), the test session was not conducted and discrimination trials were continued until the criterion for moving to test sessions was again reached. Similarly, if the criterion of 8/10 correct choices was not reached in the last 10 trials of a test session, discrimination sessions were resumed until the criterion for test sessions was achieved within a session. The introduction of this additional criterion was based on the observation that if multiple errors were made in either a discrimination or a test session, cows often took some time to recover accuracy, and poor accuracy could continue into the following session.

Seven to eight test sessions were conducted for each cow (see Table 1). Cow 4840 completed eight test sessions because she had failed to reach the criterion on her first test session. Cow 0315 completed eight test sessions and the remaining two cows completed seven test sessions each.

Transfer session. After the completion of test sessions, a transfer session was conducted for each cow. Food was prepared daily and was mixed and delivered in the same proportions as mentioned above. Sessions were conducted by two experimenters 8.30 am Monday to Friday. Each cow completed one session of 12 trials in one day of testing. Typical session duration was around 30 min. A yellow stimulus could be hung from the pipe fencing so it was positioned at the end of one of the runs. Placement of the yellow stimulus was changed according to a quasi-random series. The yellow stimulus always signalled that food was available in that run, and the unmarked runs always signalled that no food was available. Trial duration and responses made were recorded on data sheets.

To begin a trial, a cow was moved to the start point and oriented towards the four runs before she was released (see Figure 4). Trial duration was timed from the start/release point and ended when the cow's shoulder had passed into the run selected. She was given about 30 s to eat the food before being walked back to the start for the next trial. While the cow was walking back to the start point, food was replaced (after correct responses) and the location of the food and the yellow stimulus was changed for the next trial (after all responses). If an incorrect response was made the cow was walked around to the start point for the next trial.

Table 1.

The total number of sessions and trials completed by each cow.

Cow	Condition	Sessions	Trials	Total trials
315	Training 1	3	30	90
	Training 2	2	40	80
	Training 3	3	40	120
	Discrimination sessions	9	50	450
	Test trials	8	10	80
	Transfer session	1	12	12
6902	Training 1	3	30	90
	Training 2	2	40	80
	Training 3	2	40	80
	Discrimination sessions	13	50	650
	Test trials	7	10	70
	Transfer session	1	12	12
4840	Training 1	3	30	90
	Training 2	3	40	120
	Training 3	3	40	120
	Discrimination sessions	28	50	1400
	Test trials	8	10	80
	Transfer session	1	12	12
7841	Training 1	3	30	90
	Training 2	2	40	80
	Training 3	6	40	240
	Discrimination sessions	11	50	550
	Test trials	7	10	70
	Transfer session	1	12	12

Results

Cow performance was analysed by calculating the percentage of correct responses (number correct per session x 100) across all experimental conditions (training, discrimination and test sessions). These data are presented in Figure 6. The dashed horizontal line indicates the criterion of 80 % correct and the dashed vertical lines indicate condition changes between each training stage and the discrimination sessions. The training and discrimination session data are represented by closed circles (●) and the test session data, on trials involving both the yellow and grey stimuli, are represented by open circles (○).

During Training 1 (T1) responses were around 75 % correct with the exception of 0315 who responded below this for her initial session and 6902, who initially responded at 100 %, as the open or partially open gates were always chosen during the first training sessions. Accuracy was generally above 80 % correct during T2 for all cows. Performance during T3 decreased slightly as the angle of the open gate was reduced, but did not drop lower than around 60 %. More training trials were completed by 7841 due to variability in her data.

During discrimination sessions, all cows showed an initial decrease in accuracy. After four sessions, 0315 was responding at and above the criterion, while responding for the remaining cows fluctuated either around this level (4840 and 7841) or below this level (6902). Cow 4840 completed a test session on day 27, but accuracy was not maintained during her following session, so discrimination sessions were resumed for 12 sessions until the criterion to proceed to test trials was again reached. Therefore, 4840 completed more discrimination sessions than the other cows. During test sessions, accuracy was above criterion for all cows.

Test trial data are presented in Figure 7 as the number of times the yellow and grey stimuli were selected from 10 presentations per yellow and grey test session. The mean of these data is also shown. Figure 7 shows that during yellow only trials in each yellow test session, cows selected the yellow stimulus with the exception of 6902, who selected yellow five times in her last two sessions (i.e., she selected yellow and the gate with no stimulus equally). During grey only trials in each grey test session, cows tended

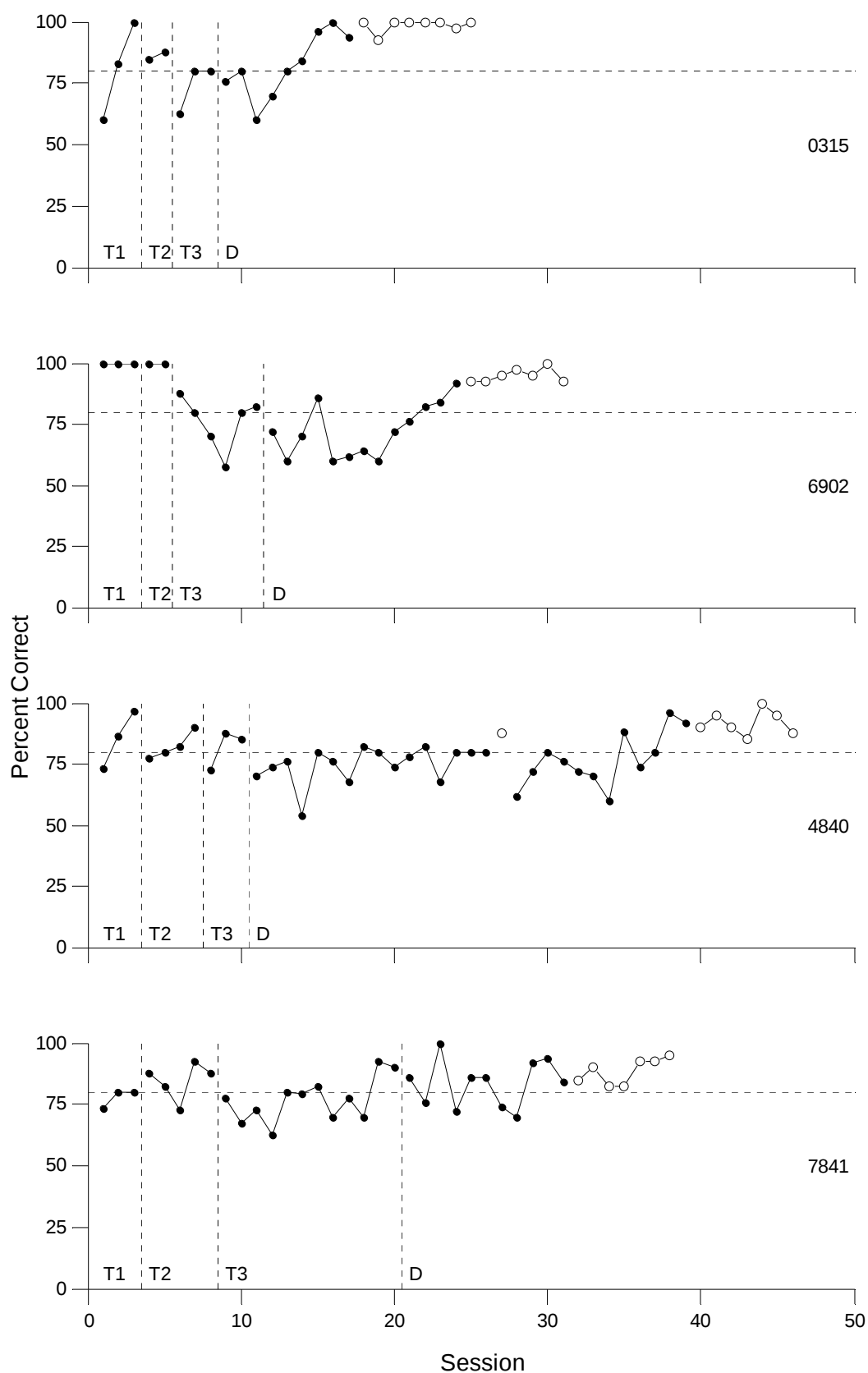


Figure 6. Percent correct across training (T1=Training 1, T2= Training 2, T3= Training 3) and discrimination sessions (D) (closed circles (●)) and test sessions (open circles (○)).

not to select grey, but selected the gate with no stimulus. Two cows (0315 and 7841) selected grey and the no stimulus gate an equal number of times in their first and second grey test sessions respectively, but then selected the no stimulus gate in the rest of their grey test sessions. Test trial data are also given in Tables 2 and 3 as the total number of yellow and grey test trials completed in all test sessions and the total number of selections of the yellow/ grey stimulus or the no stimulus gate during yellow only trials in yellow test sessions and grey only trials in grey test sessions. These tables also show that the yellow stimulus was generally selected on yellow only trials and the no-stimulus gate was most often selected on grey only trials.

A paired samples t test (SPSS 16.0 for Windows) was used to compare the mean number of selections of the yellow and grey stimuli over test trials. This result was significant $t(3)=9.854$, $p<.05$. Yellow was selected more ($M=8.1$) than grey ($M=3.2$).

Trial duration was analysed by calculating the average duration on both correct and incorrect trials and left and right trials. Figure 8 shows these data across training and discrimination sessions. All cows took longer to select a stimulus and gate during initial training. Trial duration decreased during the discrimination sessions for all cows, with the exception of 6902, for which time to complete a trial initially increased from T3. Visual analysis of Figure 8 shows that left and right trials and correct and incorrect trials were of similar duration.

Figure 9 shows trial duration for correct and incorrect trials for each cow on yellow only trials in yellow test sessions and grey only trials in grey test sessions. Cows maintained similar trial duration throughout the test sessions. Correct and incorrect test trials were of similar duration.

Table 4 shows the trial by trial data during the transfer session, with the correct position of the yellow stimulus (in runs 1-4) for each trial. Correct trials are represented by C, which indicates correct run selection, i.e., the stimulus was presented in the same run that was chosen. Incorrect trials are represented by the numbered run which was incorrectly chosen. One cow (0315) selected the yellow stimulus correctly nine times from 12 trials (75 % accuracy). Cow 6902 achieved four correct trials (33 % accuracy) and 7841 achieved six correct trials (50 % accuracy). Cow 4840 responded at chance levels (25 % accuracy).

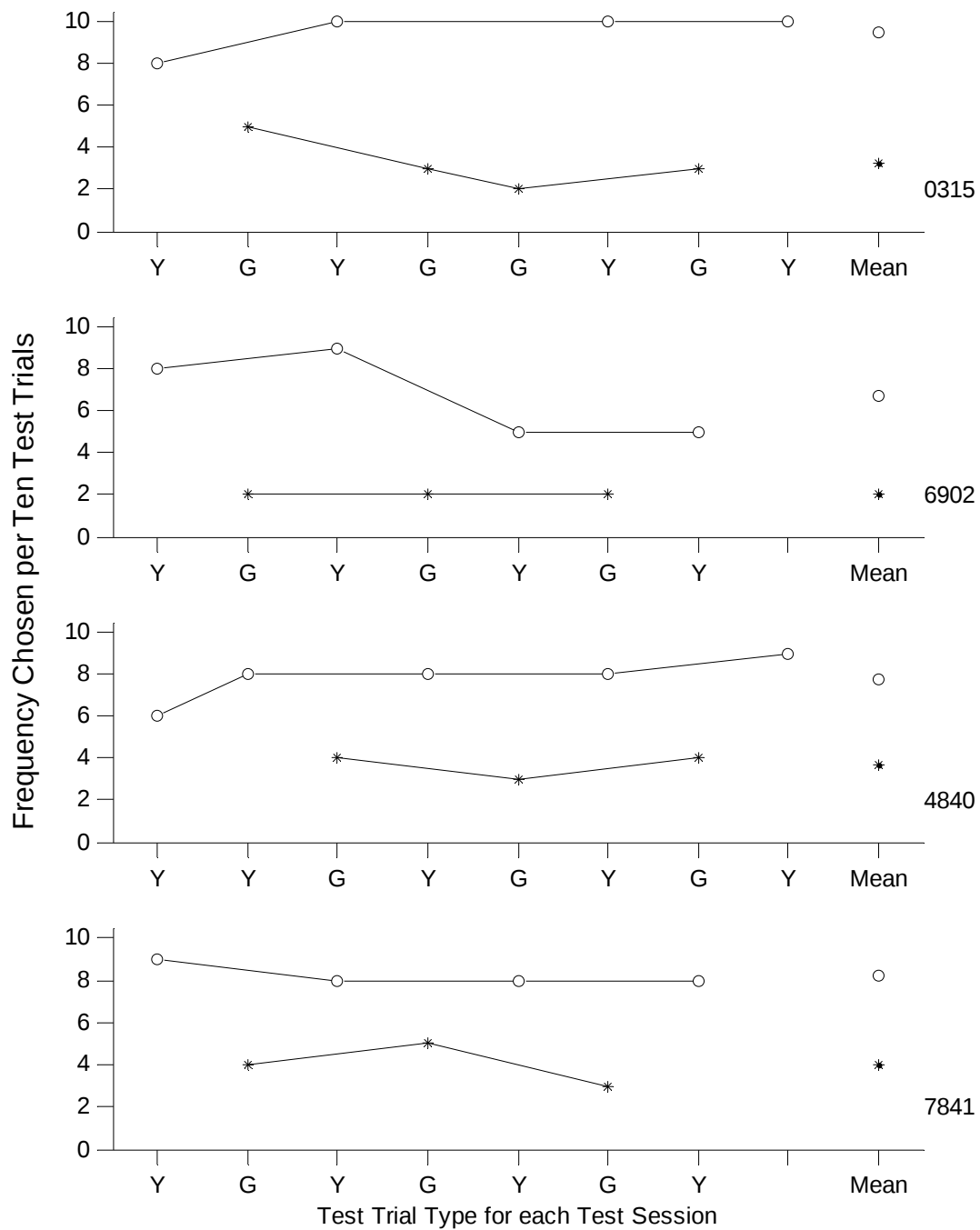


Figure 7. The number of times the yellow stimulus was selected in yellow only trials in each yellow test session (Y = ○) and the number of times the grey stimulus was selected in grey only trials in each grey test session (G = *), along with the mean number of these data.

Table 2.

Cow number, the total number of yellow only trials, the number of times yellow was selected on these trials and these data as a percentage and mean. Also shown is the number and percentage of selections of the no stimulus gate during yellow only trials in yellow test sessions.

Cow number	Total yellow trials	Times yellow selected	% yellow selected	Mean per session	Times no stimulus selected	% no stimulus selected
315	40	38	95.0	9.5	2	5.0
6902	40	27	67.5	6.8	13	32.5
4840	50	39	78.0	7.8	11	22.0
7841	40	33	82.5	8.3	7	17.5

Table 3.

Cow number, the total number of grey only trials, the number of times grey was selected on these trials and these data as a percentage and mean. Also shown is the number and percentage of selections of the no stimulus gate during grey only trials in grey test sessions.

Cow number	Total grey trials	Times grey selected	% grey selected	Mean per session	Times no stimulus selected	% no stimulus selected
315	40	13	32.5	3.3	27	67.5
6902	30	6	20.0	2	24	80.0
4840	30	11	36.7	3.7	19	63.3
7841	30	12	40.0	4	18	60.0

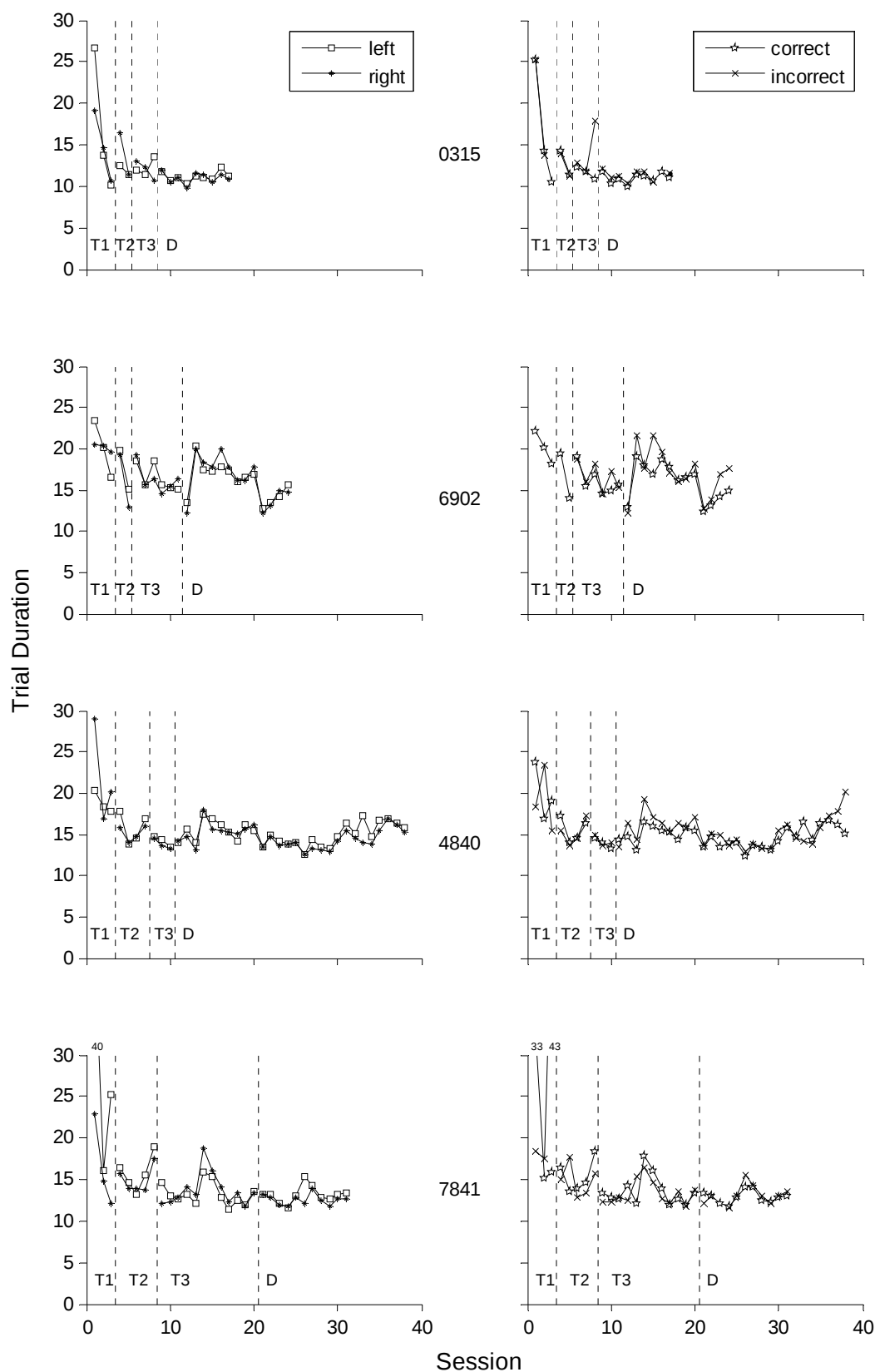


Figure 8. Average trial duration on left and right trials (left) and correct and incorrect trials (right) across training and discrimination sessions (T1=Training 1, T2=Training 2, T3=Training 3, D=discrimination trials) for each cow.

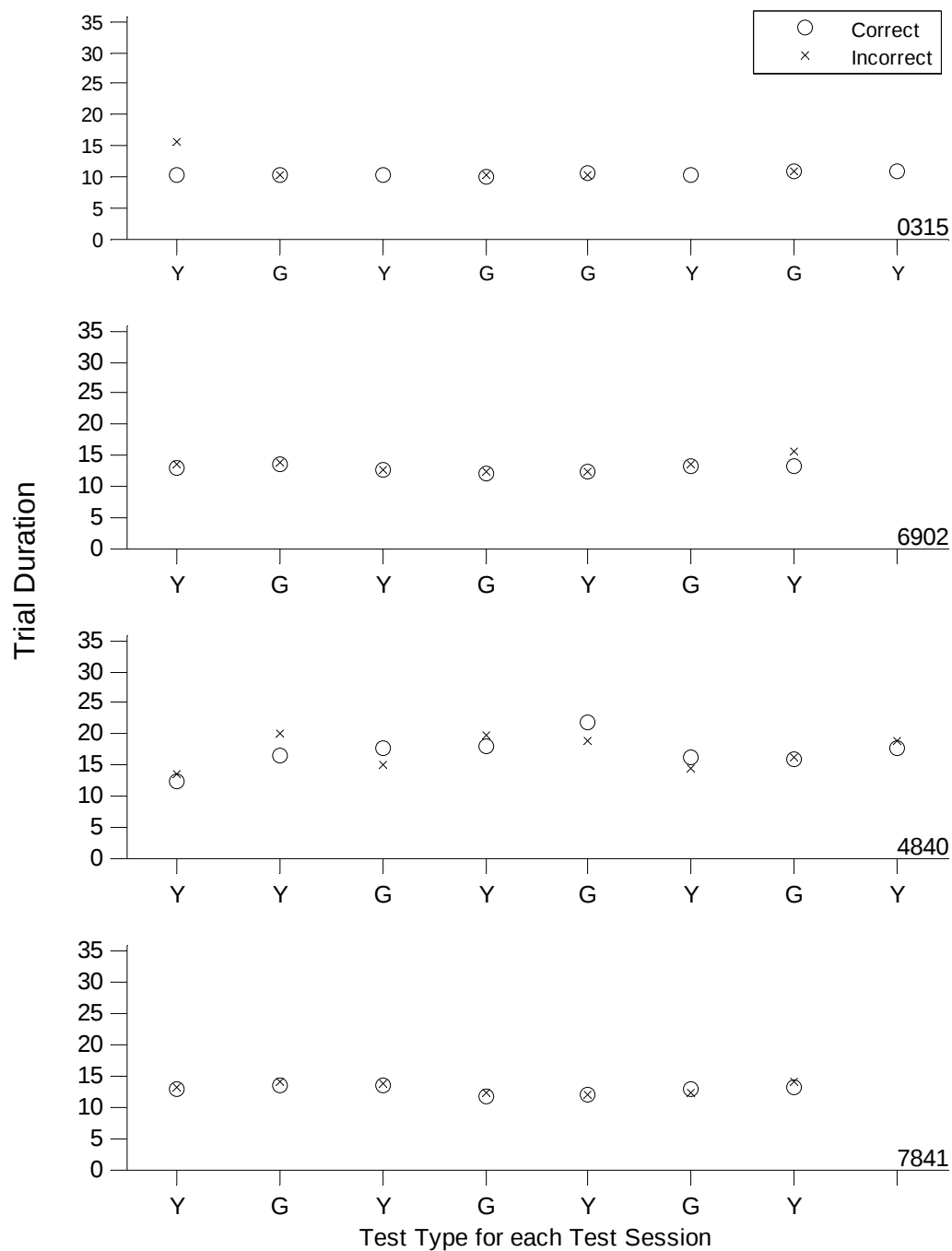


Figure 9. Average trial duration for correct and incorrect trials on yellow only trials in each yellow test session (Y) and grey only trials in each grey test session (G) for each cow.

Table 4.

Correct stimulus position (1-4), trial number (1-12) and the position selected on correct trials (C) and incorrect trials (represented by the number run chosen) during the transfer session.

Cow	315											
	Trial number											
Stimulus position	1	2	3	4	5	6	7	8	9	10	11	12
1					C		C			C		
2	3		C			C		C			C	
3		1										C
4				2								

Cow	6902											
	Trial number											
Stimulus position	1	2	3	4	5	6	7	8	9	10	11	12
1			3		2				2			
2	3					4				C		C
3		C		3			1	C			2	
4												

Cow	4840											
	Trial number											
Stimulus position	1	2	3	4	5	6	7	8	9	10	11	12
1			3			2					2	
2	1						C			1		
3		C		3	4			C	1			3
4												

Cow	7841											
	Trial number											
Stimulus position	1	2	3	4	5	6	7	8	9	10	11	12
1		3			3					1		
2	C		C			C			C		C	
3				C			3	2				3
4												

Table 5 shows the number of correct and incorrect responses made by each cow in the transfer session. Also shown is the percentage of correct responses across blocks of four trials. Percent correct for 0315 increased to 100 % after the first four trials of her session. Percent correct also increased to 50 % for 6902, but accuracy decreased for 4840. Cow 7841 was more accurate at selecting the correct arm in the first four trials of her session with 75 % correct, but accuracy decreased to 25 % and then increase to 50 %.

Table 5.

The number of correct and incorrect trials and the percentage of correct trials across blocks of four trials for each cow.

Cow 0315	Correct/ Trial number incorrect	% correct over four trials	Cow 6902	Correct/ Trial number incorrect	% correct over four trials
1	x		1	x	
2	x		2	√	
3	√		3	x	
4	x	25%	4	x	25%
5	√		5	x	
6	√		6	x	
7	√		7	x	
8	√	100%	8	√	25%
9	√		9	x	
10	√		10	√	
11	√		11	x	
12	√	100%	12	√	50%

Cow 4840	Correct/ Trial number incorrect	% correct over four trials	Cow 7841	Correct/ Trial number incorrect	% correct over four trials
1	x		1	√	
2	√		2	x	
3	x		3	√	
4	x	25%	4	√	75%
5	x		5	x	
6	x		6	√	
7	√		7	x	
8	√	50%	8	x	25%
9	x		9	√	
10	x		10	x	
11	x		11	√	
12	x	0%	12	x	50%

Discussion

Cows were successfully trained to approach the pair of gates with S+ (the yellow stimulus) when it was presented opposite the pair of gates with S- (the grey stimulus) in a simultaneous discrimination. Behaviour was shown to be under control of S+, as yellow was selected when it was presented with grey and when it was presented alone. Determination of whether discriminations are acquired through response-selection or stimulus-approach can be ambiguous, however, the current results suggest that cows may learn discriminations using stimulus-approach, as S+ was approached and S- was largely avoided, particularly in test trials. Transfer of learning did not occur in a new location and with a different context, indicating that this training was not enough for the yellow stimulus to act as a signal that food was available when the location and some features of the apparatus were the same.

All cows achieved the criterion on the simultaneous discrimination task. Once correct responding had reached 80 % or above, this level was generally maintained over three consecutive sessions, with some cows achieving over 90 % correct. These results support previous research demonstrating cows can learn such a discrimination (e.g., Baldwin, 1981; Entsu et al., 1992; Rehkamper & Gorchach, 1997; Rybarczyk et al., 2003; Schaeffer & Sikes, 1971; Taylor & Davis, 1998; Wieckert et al., 1966). The current findings also support previous research suggesting that cows can discriminate yellow from grey (e.g., Dabrowska et al., 1981; Riolo et al., 1989; Soffie et al., 1980; Thines & Soffie, 1977) and that cows can learn to locate food when it is paired with visual cues (e.g., Kidunda & Rittenhouse, 1992; Howery et al., (2000); Renken et al., 2008).

Test trials were presented to examine the hypothesis that cow behaviour would come under stimulus control of S+. As Rachlin (1970; 1976) suggested, varying aspects of S+ or S- is one method that can be used to determine which of these stimuli is controlling behaviour, if not both. In this case, stimulus presentation was altered by removing one of the stimuli during test trials. All cows continued to approach S+ during these trials, confirming the assumption that S+ would exert greater control over behaviour than S-. When presented with S- alone, cows did not approach S-, but rather approached the gate with no stimulus present. These results are suggestive that cows had

not learned about only S+ or S-, but had learned something about both S+ and S-, as approach behaviour was shown towards yellow but cows did not approach grey.

Behaviour seen during test trials could be interpreted in several ways. Firstly, when presented with S- alone, cows could have responded at chance levels (50/50), which would suggest that they had not learned not to approach grey. While this did occur for two of the 13 grey test sessions, selection of the gate with no stimulus when it was presented with S- was more frequent than selection of S-. Both options gave access to food during test trials, so despite selection of S- gaining access to food, cows still selected the other option. This supports the suggestion that some control was shown by S-, and that cows *had* learned not to approach grey. Secondly, during test trials, cows may have learned to approach whichever gate had a stimulus (board) present. However, if discriminations were being made on the basis of stimulus present or stimulus absent, cows may have been expected to approach S- during grey test trials, as the shape of the board was at least common to the original S+. Given the current data, this possibility does not seem likely, as if this was occurring, selection of the gate with no stimulus would have never occurred. In fact, the no stimulus gate was approached more than S-. Finally, the discrimination learned may have been not to approach S-, which, based on the results, seems the best interpretation of the behaviour shown.

Other studies of discrimination involving an S+ and S- have also shown that animals learn not to respond to S-. Kendall and Mills (1979) found that when presented with variations of the original training stimuli, pigeons trained with an S+ with colour and shape pecked at the S+ with colour and shape most often, followed by the colour of the S+ alone, but did not peck the S- colour alone, and did not peck the S+ shape even when it was presented with the S- colour. Similarly, Reynolds (1961) showed that a negative stimulus elicited no responding in pigeons, and Taylor and Davis (1998) reported that cattle showed significantly higher responses to an S+ handler and few (or no) responses to an S- handler. During test trials, cows in the present study made fewer responses to S-, both when it was presented with S+ and when it was presented alone, supporting these previous findings.

Theorists such as Mackintosh (1974) explain discrimination learning in terms of either response-selection or stimulus-approach. Mackintosh suggests that, in particular, simultaneous discriminations are learned primarily through stimulus-approach. Although

stimulus-approach and response-selection are theoretically different in their underlying mechanisms, their similarity means it is difficult to determine which one has resulted in the acquisition of the behaviour. Cow behaviour in the current experiment could be explained in terms of either stimulus-approach or response-selection. For example, response-selection states that the yellow/grey discrimination was solved by selecting left when the stimulus configuration was yellow/grey and selecting right when the stimulus configuration was grey/yellow. Stimulus-approach describes the same behaviour as approaching yellow and not approaching grey. While it is possible that behaviour could be interpreted using either process, the current results appear more demonstrative of stimulus-approach, where in the presence of yellow, cows consistently selected yellow. In the absence of yellow, cows chose not to select grey. The interpretation of this behaviour seems more difficult in terms of response-selection.

An attempt to achieve transfer of learning across situations was not successful in the current experiment. Considering the number of trials in which cows had learned to approach yellow, it was expected that selection of the yellow stimulus would also be seen in a new context. In spite of the fact that cows moved reliably to push through the S+ gates in test sessions, this stimulus control did not carry over into the transfer session. Cows did not undergo a true test of generalisation, as reinforcement, and therefore training, was given on the completion of all correct responses in the new setting. As such, if transfer was shown, there was an expectation that the percentage of correct selections of the yellow stimulus would have increased over the 12 transfer trials. However, no good evidence for transfer was seen, as only one cow (0315) showed an improvement in her percentage of correct responses. One cow (6902) showed a slight improvement in responding, but the remaining cows either showed no improvement or got worse at the task.

The transfer task was essentially the same (i.e., approach yellow) and additional stimuli (i.e., feed bowl, bracket and tray, yard fencing) were at least common to the original setting in which training took place (i.e., the yard). However, stimulus presentation was different in the new setting, in that, the grey stimulus was removed, and the yellow stimulus was attached to the yard fencing above a feed bowl instead of being presented on gates. The electric fence tape used was also different to the pipe fencing within the yard area. These changes could have made the task different enough to affect

transfer of learning. Previous research (i.e., de Passille et al., 1996; Munksgaard et al., 1997; Rushen, et al., 1998) has reported mixed results when investigating the ability of cattle to generalise learning across locations. Therefore, the issue of achieving generalisation across locations will be further addressed in a later experiment (Experiment 5).

When learning an AMS, cows must discriminate a variety of stimuli. The results of the current experiment confirmed that cows can learn to attend to a visual cue in an experimental setting similar to what they may encounter on an AMS farm. These findings show that there is potential for visual cues to be used as a ‘sign’ or signal to a correct path, which may be able to reduce the time spent learning an AMS gate system.

As previously mentioned, a feature of AMS farms in New Zealand is that cows must change previously learned responses when faced with changing situations. Cows on an AMS farm may need to change learning of one path to reach the dairy, but are then faced with re-learning a new path which is regularly changing on a daily basis in accordance with the practice of pasture rotation. The current experiment showed that signs were effective, within the training setting, at signalling the correct path. Therefore, Experiment 2 aimed to expand this by examining whether cows could learn to reverse a previously learned correct path and also whether signs might aid this process.

Experiment 2

As discussed previously, regular pasture rotation means that cows on AMS farms are required almost daily to locate a new path to the dairy. One method of examining the ability to change a previously learned response is to present an animal with a reversal learning task.

Reversal learning is commonly used to measure learning ability (Sappington, McCall, Coleman, Kuhlert & Lishak, 1997), and is often referred to as learning to learn (Candland, 1968). In reversal learning experiments, animals are typically presented with a two-choice discrimination task, such as used in Experiment 1, where responses to an S+ are reinforced and responses to S- are not reinforced. Once correct responding has reached a criterion, a reversal occurs where the previous S- becomes S+. The animal is then tested to discover the number of trials needed before correct responding shifts to the new task. Learning ability is assessed by analysing performance over repeated reversals, with an expectation that errors will decrease as the number of successive reversals increase. Reversal learning has been investigated in a wide variety of species, including rats (North, 1950), monkeys (Cole, 1951; Harlow, 1949), alligators (Davidson, 1966), octopus (Mackintosh & Holgate, 1965), paradise fish (Warren, 1960), cats (Cronholm, Warren & Hara, 1960), ducklings (Heaton, 1978), pigs (Moustgaard, Arnfred, Lind, Hansen & Hemmingsen, 2004) and horses (Fiske & Potter, 1979; Martin, Zentall & Lawrence, 2006; Sappington et al., 1997; Warren & Warren, 1962).

In reversal learning experiments, the best performance an animal can achieve is to make one error before learning that a reversal in responding is required for the next trial, as the animal has to make at least one error to discover that a reversal has taken place. Harlow (1949) showed that monkeys could reverse a learned discrimination after one trial. He trained monkeys to discriminate between two stimuli for a maximum of 11 trials, and then reverse this discrimination for a further eight trials. The first trial after a reversal had taken place was regarded as the informing trial, and the following trial (i.e., the second trial after the reversal) was regarded as the measure of how well the animal had learned that a change in response was required. Harlow showed that monkeys could reverse responding after the informing trial, and were able to respond correctly on the

second trial after the reversal, demonstrating best performance. For most mammals, as the number of reversals increase, there is an improvement in responding (Walker, 1987). However, this has not been shown for all species, e.g., isopods (Thompson, 1957), crabs (Datta, Milstein & Bitterman, 1960) and paradise fish (Warren, 1960). Although it is probably inappropriate to rank animals on a single scale of learning ability, clearly differences exist among species.

Only a few studies have measured reversal learning in large animals. A handful have investigated reversal learning in horses (i.e., Fiske & Potter, 1979; Martin et al., 2006; Sappington et al., 1997; Warren & Warren, 1962), and have reported mixed results. Warren and Warren (1962) trained two horses to select either a white box (positioned left) or black box (positioned right) located in a paddock. The non-preferred stimulus was selected as the initial S+, although how this preference was determined was not reported. The best reading of their experiment suggests that the position of the boxes did not change, but the S+ colour was reversed. They reported that horses achieved six to nine reversals, and a reduction in errors over successive reversals was seen, as is typical in reversal learning tasks. Fiske and Potter (1979) also trained horses to discriminate stimuli on the basis of brightness and spatial cues. The initial discrimination required 26 horses to respond to a black bucket positioned right in a Y-maze, which was then reversed to a white bucket positioned left. Daily reversals of the S+ colour continued until all horses had completed 20 reversals. As with Warren and Warren's (1962) study, a reduction in the number of errors over successive reversals was shown.

While these early studies demonstrate reversal learning in horses, more recent studies have reported mixed results. Sappington et al. (1997) presented 17 horses with a black and white bucket in a test stall. The S+ (black/white) colour was reversed and the position (left/right) of the buckets was also varied. Reversals occurred after a criterion of 80 % correct over two consecutive sessions was met. Horses in their study successfully reversed on four occasions over 19 sessions. On the basis of this result, the authors concluded that reversal learning may be a difficult task for horses to learn. Martin et al. (2006) also combined spatial and visual cues in a reversal task. Horses in a spatial group were required to select a stimulus box positioned either right or left, and reverse responding to the other position after a 90 % correct criterion was reached. Horses in a

visual group were required to select the lit (or not lit) light to the same criterion, after which they then had to reverse this discrimination. Post reversal, horses in the spatial group successfully reversed only six times and horses in the visual group did not learn to reverse responding. While the salience of the visual cue used (a projected light) was questioned, both Martin et al. (2008) and Sappington et al. (1997) suggested visual cues increased the difficulty of a reversal learning task. Greater difficulty with the reversal of visual discriminations has also been reported in pigs (Moustgaard et al., 2004).

To the authors' knowledge, only Lensink, Veissier and Boissy (2006) have investigated reversal learning in cattle. They assessed whether calves could learn to reverse a response in a T-maze. In their study, selection of the correct arm of the maze sometimes resulted in access to food and sometimes resulted in access to social reinforcement (the presence of other calves), although how many times food or the calves served as reinforcement was not mentioned. The correct arm was the same arm of the maze for the first two of three sessions and was then reversed to the other arm of the maze for the third and final session. They showed that all calves were able to complete one reversal, but did not test beyond this.

While research on reversal learning in cattle is scarce, it has been suggested that cattle show resistance to changing a previously learned response. For example, in a farm setting, consistent side preferences in milking sheds have been observed in individual dairy cows (Hopster, van der Werf & Blokhuis, 1998; da Costa & Broom, 2001). Further support for this claim has come from two studies. In the first, Grandin, Odde, Schutz, and Behrns (1994) presented two different handling treatments (free walk through or restraint) at each end of a Y-maze. When heifers were allowed to choose freely, the walk side of the maze was chosen more than the restraint side, however, when the treatments were switched, heifers did not switch responding, and more choices to the restraint side were seen. This failure to switch responding to the walk side was seen as a resistance to change a previously learned response. In the second, Hosoi, Rittenhouse, Swift and Richards (1995a) placed food in the ends of both arms of a Y-maze and recorded whether choices to an arm changed relative to food availability. Three trials were conducted; on the first trial, cows were allowed to consume half of the food in the chosen arm, on the second trial the unconsumed food remained in the arm first visited and half the food was

removed from the un-chosen arm, and on the third trial no food was present in the previously visited arm (if it had been chosen on the preceding two trials) but food was present in the previously un-chosen arm. Hosoi et al. (1995a) hypothesised that once the food had been consumed in one arm, cows would shift responding to the previously un-chosen arm, however, cows continued to choose the previously visited arm on the third trial and did not change their selection.

It would seem premature to make assumptions about the ability of cows to reverse previously learned responses on the basis of these two studies. Grandin et al. (1994) used very few trials, which may have confounded their results. Fourteen trials were completed, of which eight trials presented a walk/restraint configuration, and six trials presented a restraint/walk configuration. Therefore after one reversal, heifers were expected to show a change in responding within six trials. Similarly, Hosoi et al. (1995a) also used few trials. Despite their cows completing 103 trials over the whole study, only three trials were conducted per session, where the test for a change in behaviour was on the third and final trial. They expected that cows would change responding on the third trial, but they did not. From a behavioural viewpoint, it seems plausible that, in accordance with the law of effect, an animal will continue to choose the arm of a maze that previously resulted in reinforcement. Therefore, it seems that other explanations of behaviour may be offered in both of these cases, and there may be no need to conclude an inability for cows to learn to reverse their choice. With the lack of research in this area, whether or not cows can learn a reversal task is questionable.

One way to measure reversal learning in animals is to use a T-maze. The T-maze is a simple maze design, which consists of a single central alley where two arms converge at a choice point and the cross of the T extends to a left and right arm. Stimuli can be placed at one, or both ends of the maze and responses are measured by recording which arm is chosen (Rachlin, 1970). As such, the T-maze provides information as to which stimuli can and cannot be discriminated. T-mazes have been used to measure reversal learning in rats (North, 1950), newts and terrapins (Seidman, 1949), isopods (Thompson, 1957), paradise fish (Warren, 1960) and cats (Cronholm et al., 1960), but few studies have used T-mazes with large animals. Heird, Lokey and Cogan (1986) examined whether or not horses could complete a spatial and discrimination task in a T-maze. The

place task required that horses locate food placed in alternate arms of the maze, and the discrimination task required discrimination of a yellow and black diagonal stimulus that marked the random location of food. Horses performed well at both tasks, achieving accuracy at over 80 % correct. T-mazes have also been used to assess foraging in sheep and goats (Hosoi, Swift, Rittenhouse & Richards, 1995b), preference in pigs (van Rooijen & Metz, 1987) and as mentioned above, learning in calves (Lensink et al., 2006).

Some studies using T-mazes have reported laterality effects (response biases). A response bias can be seen when a subject responds more to one alternative than to another alternative, irrespective of stimulus presentation (Reber & Reber, 2001). Kight, Steelman, Coffey, Lucente and Castillo (2008) showed that giant water bugs showed a left side bias when swimming through a T-maze, and lateral preferences have also been reported in sheep and goats (Hosoi et al., 1995b) and pigs (van Rooijen & Metz, 1987) responding in a T-maze. Studies investigating reversal learning in horses have not reported response biases, but previous research has indicated that side biases (e.g., da Costa & Broom, 2001; Hopster et al., 1998) and a resistance to change responses (e.g., Grandin et al., 1994; Hosoi et al., 1995b) may be prevalent in cattle. From these studies, it is not clear if response biases will affect the learning of a reversal task by cattle.

One New Zealand farms, cows are faced with more than one choice point on their journey to reach the dairy. At minimum, cows are faced with a T-maze and must make a choice either right or left to exit pasture. Therefore, a simple T-maze, as an approximation of what cows actually experience on farms, was used to investigate reversal learning. As in Experiment 1, it was desirable to create experimental conditions that were both realistic to what cows experience on farms while maintaining control in order to meet experimental requirements. Experiment 1 demonstrated that a yard area was appropriate for this use; therefore T-mazes were constructed in the same yard area used in the previous experiment.

The aims of the current experiment were two-fold. One aim was to assess the ability of cows to learn a reversal task. To measure this, cows were initially trained to select one arm of a T-maze before a reversal was required to the previously unreinforced arm. The first experimental condition involved a reversal from one session to the next provided a criterion of 88 % correct was reached in a session. Cows were required to

reverse responding within the session during a second condition, and reverse responding within the session in two new T-mazes in a third and fourth condition. The second aim was to expand the findings of Experiment 1 and determine whether cows could learn to select a visual discriminative stimulus and use it to improve performance in this reversal task. To assess this, two cows were presented with a visual cue, or sign, in the T-maze, and two cows were not. It was expected that the sign would come to control behaviour and that cows given this sign would approach the arm in which the sign was presented. It was hypothesised that the two cows in the visual cue group would be faster at reversing responses and would make fewer errors than the two cows in the non-visual cue group.

Method

Subjects

Two Friesian-cross (0386 and 9610) and two Jersey (8522 and 6525) dairy cows participated in the experiment. All cows were approximately three years old and were experimentally naive. Housing and maintenance was the same as for Experiment 1.

Apparatus

Trials were conducted in the same holding yards used in Experiment 1. Small modifications were made to the yard area with the addition of several newly fabricated gates that could be opened and closed to form simple maze patterns. Three single T-maze patterns were created, each at a different location within the test area. The base of T-maze 1 measured 1.5 m wide by 6 m long and the arms of the T were about 3 m wide by 9 m long. The base of T-maze 2 was 1 m wide by 4 m long and the arms were about 1.5 m wide by 9 m long, and the base of T-maze 3 was approximately 2 m wide by 4 m long and the arms were 3 m wide by 9 m long. Figures 10-12 show the layout for each T-maze used.

Stimuli were the same as used in Experiment 1; however, stimulus presentation differed in that a single yellow board was used. The yellow stimulus was attached to the yard fencing by hooks and was positioned above a feed bowl. All other equipment (i.e., feed bowls, rubber matting, stopwatch, data book) were the same as for Experiment 1.

Procedure

Session time and duration, separating of cows into pairs and the amount and type of food delivered were the same as for Experiment 1. One pair of cows (8522 and 0386) were presented with the visual cue/sign (termed here sign cows) and the other pair (6525 and 9610) were never presented with the visual cue/sign (termed here no-sign cows). For the sign cows, the yellow stimulus was presented at the end of one arm of the T-maze above a feed bowl containing food. Selection of that arm was always reinforced. No yellow stimulus was present in any arm for the no-sign cows, but a feed bowl containing food was placed in the correct (but unmarked) arm. Selection of that arm always resulted in access to food. Selection of the incorrect arm for both the sign and no-sign cows did

not result in access to food. A small plastic container was placed behind both feed bowls and held a small portion of food to control for the possibility that discriminations were being made with the aid of olfactory cues.

The procedure was the same for each T-maze. At the start of a trial, a cow was moved to the start (S on Figures 10-12). From here she had to walk up to the choice point at the top of the T and then move into the left or right arm. So as not to influence responses, the experimenter waited at the start of the maze until the cow had moved into one of the arms. On correct selection of an arm, the cow was given about 30 s to eat before she was moved around the outside of the maze back to the start for the next trial. Cows were always walked back around the outside of the T and were never allowed to walk back to the start by going through the maze itself (see right plate of Figures 10-12). If the incorrect arm was selected, a non-correction procedure was used in which cows were immediately moved on to walk back to the start of the maze for the next trial and were not allowed to retrace their steps back to the correct path to gain access to food. Once the cow had moved away and was walking back to the start, the experimenter changed the stimuli if a change was required for the following trial.

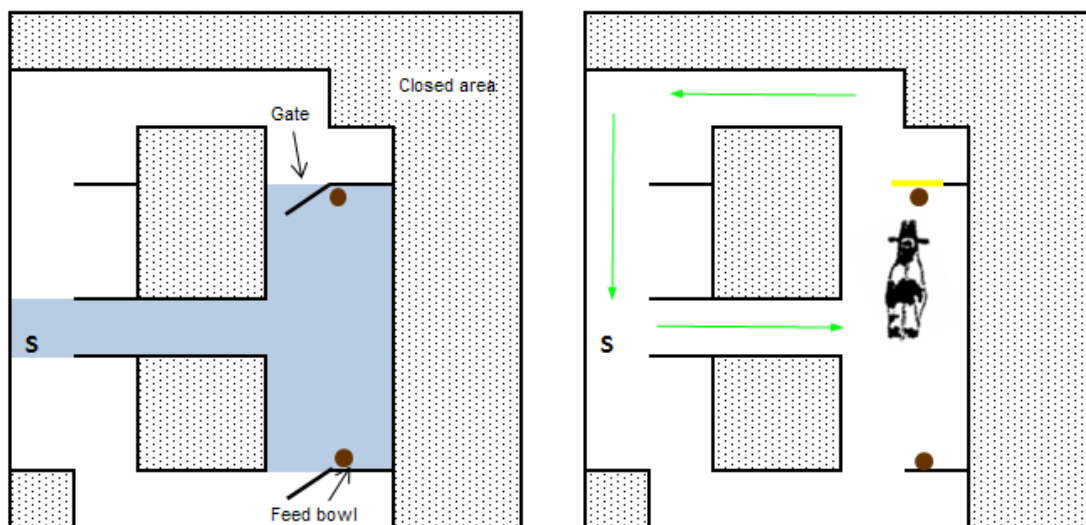


Figure 10. T-maze 1. The shaded area shows the base and arms of the T (left plate). The yellow bar (right plate) indicates the position of the yellow stimulus for a left correct trial (presented to the sign cows) and the arrows represent the path taken to respond and return to the start for the next trial.

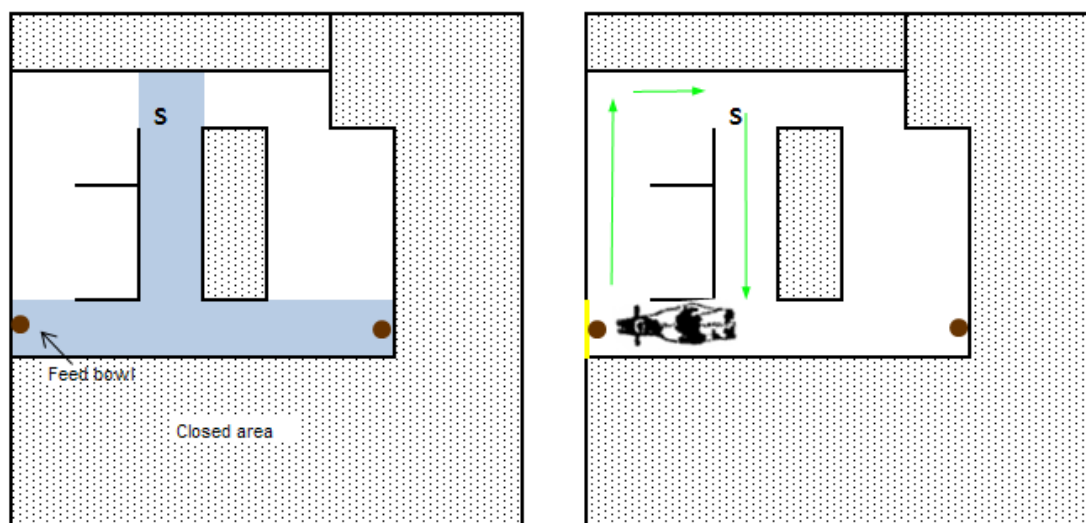


Figure 11. T-maze 2. The shaded area shows the base and arms of the T (left plate). The yellow bar (right plate) indicates the position of the yellow stimulus for a left correct trial (presented to the sign cows) and the arrows represent the path taken to respond and return to the start for the next trial.

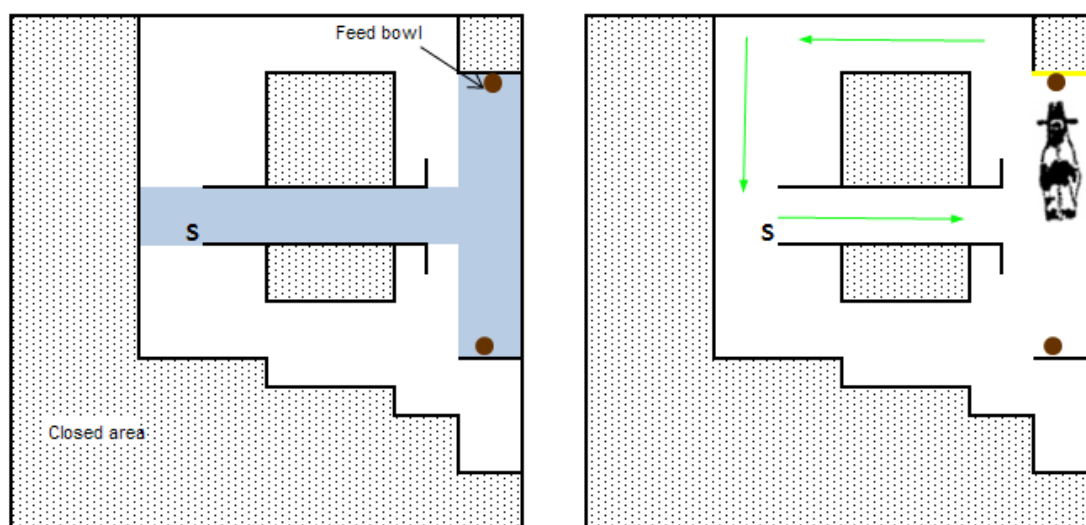


Figure 12. T-maze 3. The shaded area shows the base and arms of the T (left plate). The yellow bar (right plate) indicates the position of the yellow stimulus for a left correct trial (presented to the sign cows) and the arrows represent the path taken to respond and return to the start for the next trial.



Figure 13. Cow 8522 (left plate) and cow 0386 (right plate) eating the food after having selected the correct arm in T-maze 3.

Trial duration was timed from when a cows' shoulder passed the start point at the base of the T-maze to when her shoulder passed a gate before reaching the end of the arm chosen. For T-maze 1, this gate was approximately 2 m from the feed bowl in the left arm and 2 m from the feed bowl in the right arm, for T-maze 2, the gate was approximately 1 m from the feed bowl in the right arm, and 1 m from the feed bowl in the left arm, and for T-maze 3, the gate was approximately 1 m from the feed bowl in the right arm and 1 m from the feed bowl in the left arm. Once a cow was in the cross of the T-maze, she was allowed to change a selection and turn only *before* these points were passed. If any of these points had been passed, the arm selected was recorded and the cow was prevented by the experimenter from turning around and moving to the other arm.

Training. At the start of the study, cows were habituated to the test area by allowing them to walk around it for 15 min each day for five days. Food was available in four feed bowls placed at different locations and an experimenter was present so that cows could become accustomed to the close proximity of a person. No stimuli were present during this training.

Condition 1. Condition 1 used a reversal learning procedure in T-maze 1. For the sign cows, the yellow stimulus was positioned in one arm above a feed bowl containing food. The unmarked arm contained an empty feed bowl. For the no-sign cows, the feed bowl in the correct arm contained food and the opposite arm contained an empty feed bowl. The yellow stimulus (sign cows) and correct arm (no-sign cows) was reversed to the opposite arm for the next session when cows had selected the correct arm on 22/25 (88 %) trials within a session. As learning progressed, Condition 1 involved a reversal from one session to the next provided a criterion of 88 % correct was reached in a session. Twenty-five trials were conducted each session.

Condition 2. Condition 2 also used T-maze 1. The procedure was the same as in Condition 1 with the exception that the yellow stimulus and correct arm were reversed within the session after 12 trials, and the trial number was reduced to 24 trials per session. There were eight sessions in this condition. Four sessions involved the presentation of the yellow stimulus/correct arm in the right arm for 12 trials before reversing to the left arm. Four sessions involved the presentation of the yellow stimulus/correct arm in the left arm for 12 trials before reversing to the right arm. Each stimulus/correct arm change was presented an equal number of times to counter the development of any side biases. The change between the fourth and fifth sessions, in which the yellow stimulus/correct arm were reversed from being right/left to left/right was not counted as a reversal, however, all other reversals between sessions were counted as a reversal.

Condition 3. Condition 3 used T-maze 2, which was formed in a different location from T-maze 1. T-maze 2 was also rotated approximately 90 ° clockwise from T-maze 1. The procedure and number of trials were the same as for Condition 2 with the exception that the yellow stimulus/correct arm were reversed within the session after six consecutive correct trials. If six consecutive correct choices were not made, no reversal occurred until this criterion was reached. Each session was regarded as new, so reversals during this condition were not dependent on what had occurred in a previous session.

Condition 4. Condition 4 involved T-maze 3, which was also at a different location from both previous mazes and was in a different orientation from T-maze 2. The procedure was identical to that of Condition 3.

Table 6 shows the total number of sessions and trials completed in each condition.

Table 6.

The total number of sessions and trials completed by each cow.

Sign/ No-sign	Cow number	Condition 1		Condition 2		Condition 3		Condition 4	
		Sessions	Trials	Sessions	Trials	Sessions	Trials	Sessions	Trials
Sign	8522	19	475	8	192	2	48	2	48
	386	19	475	8	192	2	48	2	48
No-sign	6525	18	450	8	192	2	48	2	48
	9610	19	475	8	192	2	48	2	48

Results

Performance was analysed by calculating the percentage of correct responses across every successive reversal. Every change of direction (i.e., right to left arm), both within and across sessions, was counted as a reversal and included in this analysis. These data are presented in Figure 14. Percentage correct for the no-sign cows would necessarily be lower than that of the sign cows, as the no-sign cows had to make a mandatory error before learning that a reversal had taken place. The sign cows, if using the visual cue, could potentially reverse responding with no error. Therefore the first trial after each reversal was removed from this analysis in order to compare the performance of the sign and no-sign cows. The dashed vertical lines indicate changes in condition.

The sign cows showed stable responding and a high percent correct, with correct responses often at or near 100 %. This performance was maintained across conditions. More varied performance can be seen from the no-sign cows, most notably 9610, for who correct responding fluctuated within and across conditions. Cow 6525 showed more stable responding, but performance fluctuated during Conditions 3 and 4, where she made no correct responses twice after a within-session reversal.

Trial duration was analysed by calculating the average time to select an arm on correct and incorrect responses over successive reversals, as shown in Figure 15. The dashed, vertical lines indicate changes in condition. There were no systematic differences between trial duration on correct and incorrect, or left and right trials between the sign and no-sign cows. Cows were seen to pause at the choice point of the T-maze and displayed vacillating behaviour. However, this pausing did not differentially affect correct or incorrect trials, as is evident in Figure 15.

Data were also analysed by calculating the number of initial errors made for every successive reversal that occurred (i.e., all reversals were counted) (see the left panel of Figure 16). Initial errors were defined as the number of post-reversal errors made before cows learned to change and select the previously unreinforced arm. The dashed vertical lines indicate changes in condition. Figure 16 shows a decrease in the number of initial errors made for each cow across Condition 1. A clear difference between the number of initial errors made per reversal can be seen between the sign cows and the no-sign cows. The sign cows continued to make few, or zero errors across Conditions 2 to 4, whereas

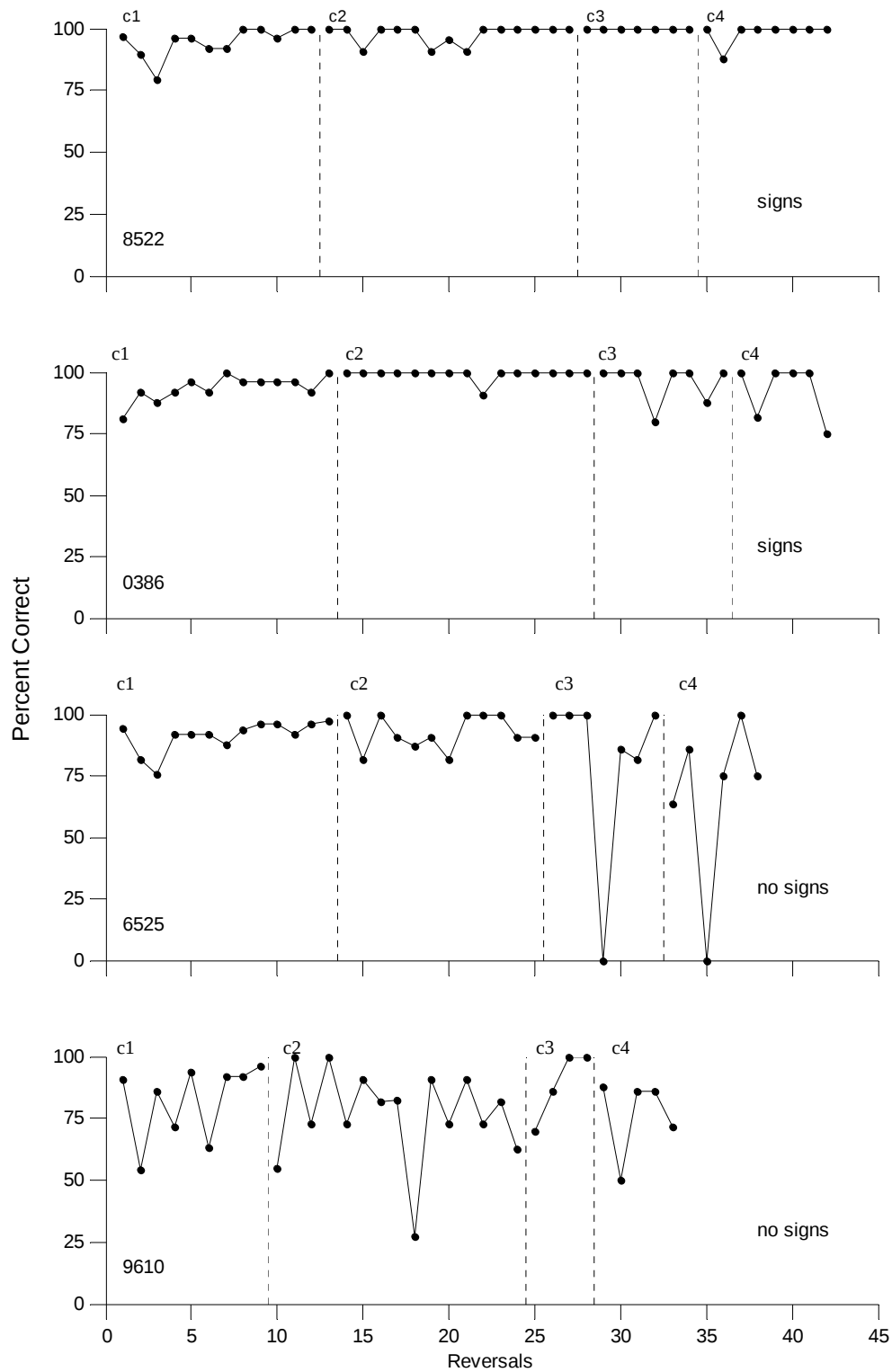


Figure 14. Percent correct over successive reversals for each cow.

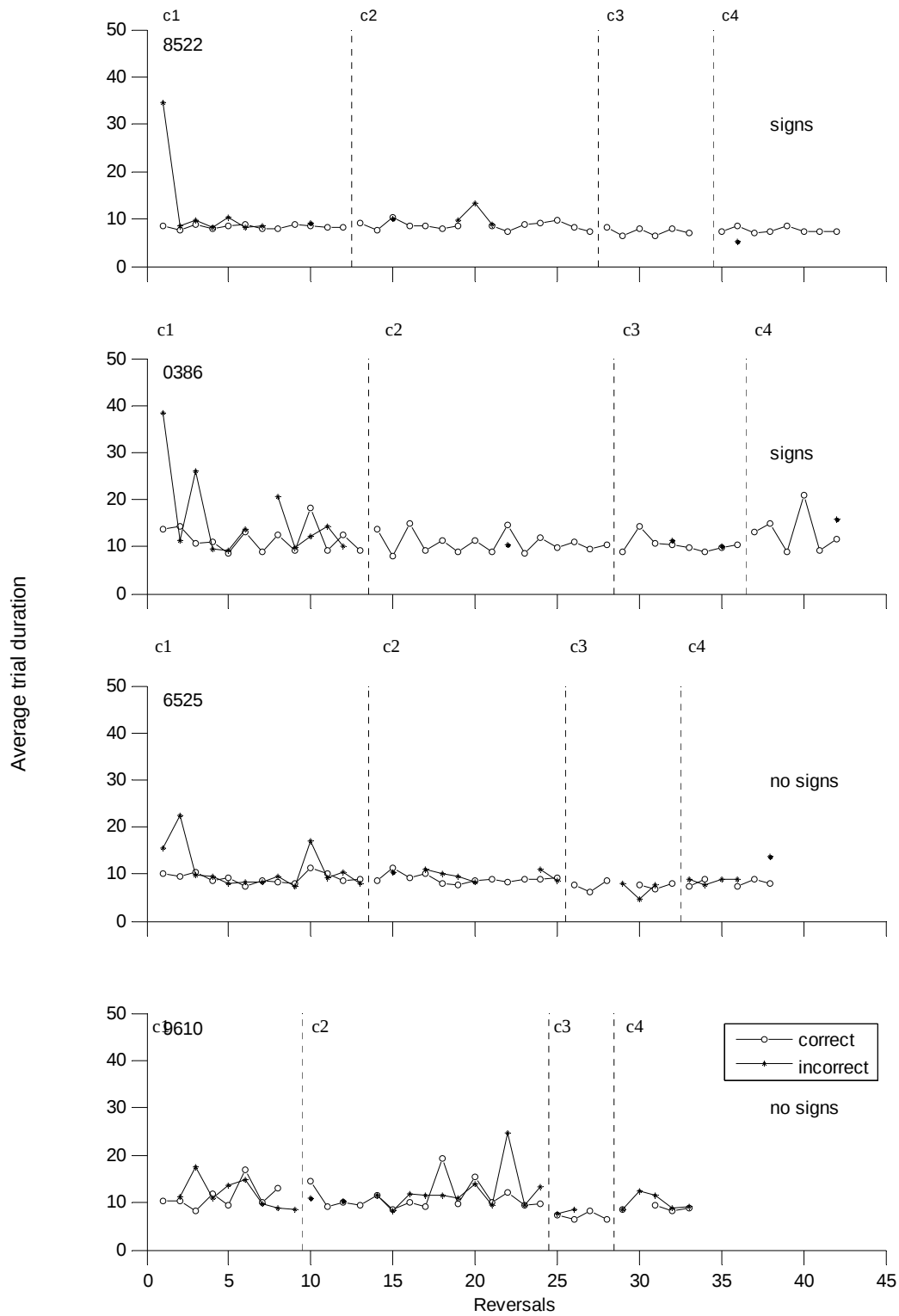


Figure 15. Average trial duration over successive reversals for each cow.

the no-sign cows made more errors, especially at the start of the experiment. This was most evident with 9610, who made more errors than 6525.

Figure 16 also shows the total number of errors made across successive reversals (right panel). Total errors were defined as the total number of errors made in one arm (i.e., to the right or left arm). There was a decrease in total errors made from Condition 1 through to Condition 4. As with the initial errors, cows presented with the visual cue made fewer total errors per successive reversal than cows not presented with the visual cue. A summary of these data are shown in Table 7 for 8522 and 0386 and Table 8 for 6525 and 9610.

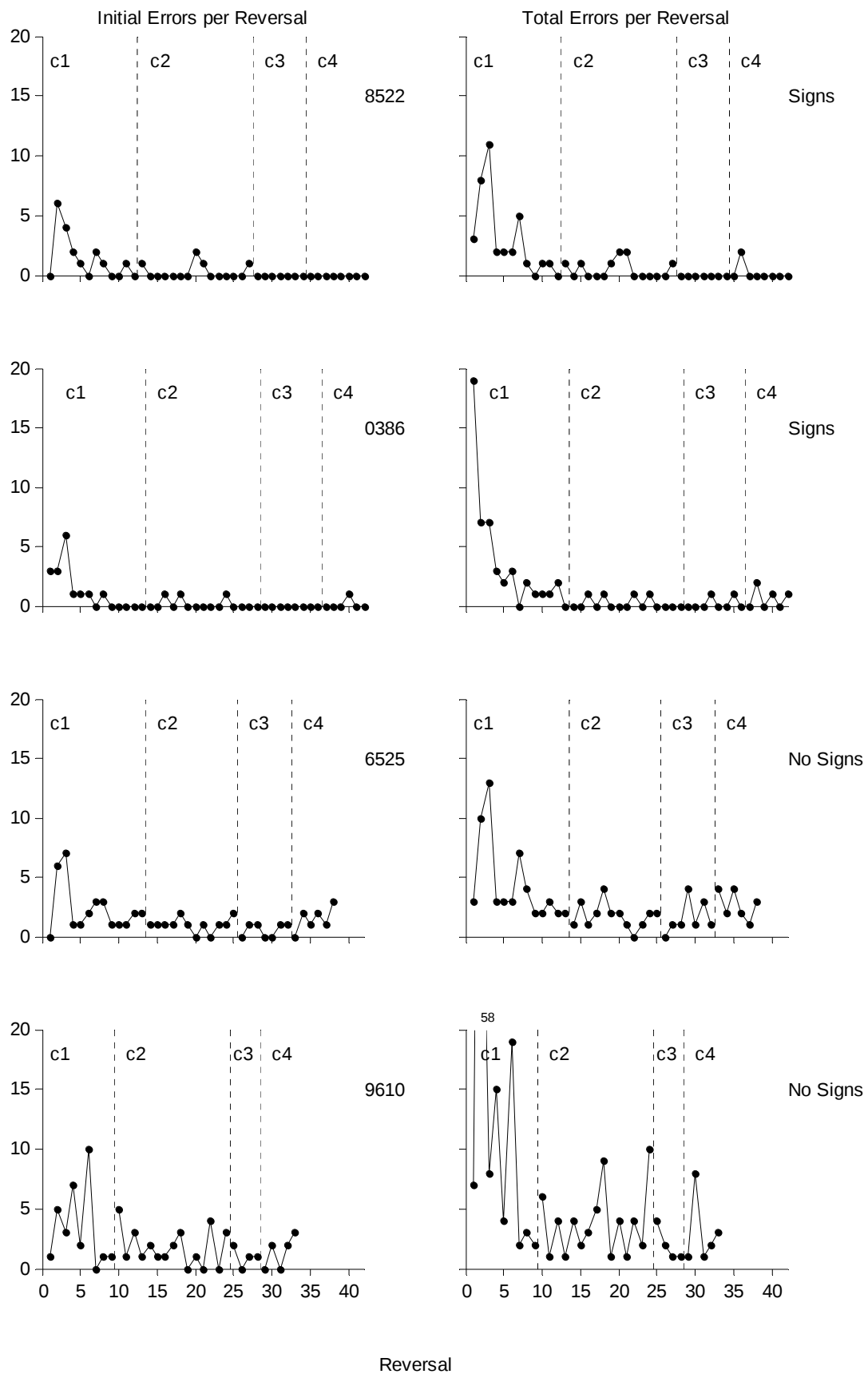


Figure 16. Initial errors made per reversal (left panel), and the total number of errors made per reversal (right panel) for each cow in Conditions 1-4.

Table 7.

The total number of reversals, total number of initial errors per reversal and total errors per reversal for 8522 and 0386 across Conditions 1-4.

Cow 8522 (Signs)				Cow 386 (Signs)			
Condition	Total reversals	Initial errors	Total errors	Condition	Total reversals	Initial errors	Total errors
C1	12	17	36	C1	13	16	48
C2	15	4	6	C2	15	3	4
C3	7	0	0	C3	8	0	2
C4	8	0	2	C4	6	1	4

Table 8.

The total number of reversals, total number of initial errors per reversal and total errors per reversal for 6525 and 9610 across Conditions 1-4.

Cow 6525 (No-signs)				Cow 9610 (No-signs)			
Condition	Total reversals	Initial errors	Total errors	Condition	Total reversals	Initial errors	Total errors
C1	13	30	57	C1	9	30	118
C2	12	12	21	C2	15	21	50
C3	7	4	11	C3	4	4	8
C4	6	9	16	C4	5	7	15

Discussion

The first aim of the current experiment was to determine whether or not cows could learn a reversal task. The data show that cows could learn this reversal task, and that the sign cows learned to reverse the selection of an arm in a T-maze with no error while the no-sign cows made more errors overall. The second aim was to determine if performance on the reversal task would be improved by the provision of a sign. Cows presented with the sign learned to attend to that cue as they reversed responding faster and made fewer errors than cows not provided with the sign.

Performance in reversal learning tasks has been referred to as an animal learning to learn (Candland, 1968; Harlow, 1949; Martin et al., 2006) and this is usually shown by a decrease in the number of errors made as successive reversals increase. An analysis of the number of errors made in the current experiment showed a reduction of errors over successive reversals. The sign cows made fewer total errors than the no-sign cows, suggesting that behaviour had come under control of the visual stimulus and the repeated reversals. The sign cows also made fewer initial errors after a reversal than the no-sign cows, showing that they were faster at responding correctly after a reversal had occurred. A reduction in errors was shown by the no-sign cows, although without the visual cue, more errors were made. A pattern of decreasing errors with reversal tasks have also been reported previously with other large animals, e.g., horses (Fiske & Potter, 1979; Martin et al., 2006; Warren & Warren, 1962), as well as smaller species, e.g., ducklings (Heaton, 1978), alligators (Davidson, 1966) and cats (Cronholm et al., 1960).

The no-sign cows were not as quick at reversing as the sign cows, but their performance was comparable to that of other species where signs were also not provided. Harlow (1949) reported that the best performance of monkeys in a reversal task was to make one error before learning that a reversal had occurred. In the current experiment, this was matched by the no-sign cows, whose best performance showed that they had, on a few occasions, learned to reverse responding after making one error. Cow 6525 achieved this on 19 out of 38 reversals, while 9610 achieved this on nine out of 33 reversals. Performance of the sign cows exceeded this, as they were able to reverse responding with no error on 31 out of 42 reversals (for both cows), suggesting that they

were reacting to the additional information provided by the visual cue. On occasion, the no-sign cows did achieve zero errors on a reversal. Close examination of the data showed that this tended to occur during Conditions 2-4 as a result of how reversals were counted for analysis (i.e., reversals were also counted across sessions as well as within). For example, if a no-sign cow was correctly selecting the left arm, and this was reversed to the right arm mid-session, she always made an error on the first trial within that session after the reversal. However, if she finished that session correctly selecting the right arm (post-reversal), the correct arm was reversed back to the left arm at the start of the following session. The following session was always conducted within one or three days (if there was a weekend) of the preceding session, therefore, occasionally, the no-sign cows simply made a correct selection on the first trial of that session, which was then counted as a reversal with no errors.

The current results contrast those of Grandin et al. (1994) and Hosoi et al. (1995a), who reported that cattle did not learn to change responding in a Y-maze. While not strict reversal learning experiments, these studies still required that cows reverse responding to the opposite arm of a maze. As mentioned earlier, their results may have been confounded by the low number of trials conducted in both cases. Grandin et al. conducted 14 trials in total. Of these, eight trials presented a walk/restraint configuration, and six trials presented a restraint/walk configuration. Hence in their experiment, heifers were expected to show a change in responding to the less aversive arm within six trials. Comparing the current data with that of Grandin et al.'s, two cows (8522 and 6525) did not correctly reverse a response within the first six trials after the first reversal. Based on Grandin et al.'s criterion, it would have been concluded that these cows failed to change responding. However, their responding improved over more trials and successive reversals. Cows in the current experiment completed over 40 reversals and over 700 trials, and the present data suggest that if Grandin et al. had increased the number of reversals and trials presented, they may have seen a change in responding by their heifers.

Hosoi et al. (1995a) conducted more trials than Grandin et al. (1994) overall, but conducted only three trials per session, of which the test for a change in responding was on the third and final trial. They found that cows showed either a random pattern of arm visits on the third trial, or a tendency to continue to visit the previously chosen arm

despite food no longer being available there due to its consumption on the preceding trials. In the current experiment, cows also did not always change responding to the previous arm within one trial (i.e., on the third trial presented), particularly in the early sessions. Even when the reversal task had been learned, the no-sign cows made one error, at minimum, before changing responding to the correct arm. The law of effect suggests that an animal will continue to choose the arm of a maze that previously resulted in reinforcement, so one interpretation of Hosoi et al.'s results is that cows behaved according to expectations, which excludes the need to suggest an inability to change responses. It seems likely that Hosoi et al.'s finding would have been different had they allowed more trials.

The current data show that cows can learn a reversal task when it is presented in a T-maze. Both the sign cows and the no-sign cows were accurate at locating food and the visual cue (sign cows) or just food (no-sign cows) in one arm of the T-maze, with three cows consistently responding at above 85 % correct. Only a small number of studies have used T-mazes with large animals. Heird et al. (1986) reported that horses achieved a high percentage of correct responses ($> 80\%$) in learning a spatial or discrimination task, and Lensink et al. (2006), while not reporting specific learning performance, showed that calves learned to select the arm of a T-maze containing either food or the presence of other calves. Therefore, the results of the current data support these studies.

When measuring behaviour using any sort of apparatus in which two or more points converge at a choice point, vacillations (moving the head back and forth or pausing at a choice point) can often occur. Vacillating behaviour has previously been reported with cattle (Grandin et al., 1994; Lensink et al., 2006) and sheep (Liddell, 1925) in mazes, and monkey's (Cole, 1951) and terrapins (Seidman, 1949) in reversal learning tasks. In the current experiment, it was observed that cows occasionally vacillated at the choice point at the top of the T before selecting an arm. This behaviour consisted of a pause of around 5-10 s, in which cows looked back and forth in both directions. While the behaviour was noted, it only occurred randomly across sessions for each cow and did not affect the average trial durations (see Figure 15).

Laterality effects have also been reported when using T-mazes, e.g., with giant water bugs (Kight et al., 2008), pigs (van Rooijen & Metz, 1987) and sheep and goats

(Hosoi et al., 1995b). Cows in the current experiment did not show any response biases to any arm of the T-maze, as shown by the consistently high percentage of correct selections. If a bias was shown, a decrease in accuracy would have been expected as a result of the bias. The absence of response biases may be due to the reversal learning task itself. Reversal learning requires continual reversals; therefore, any response biases will interfere with this learning. As Fiske and Potter (1979) suggest, animals must learn not to develop response biases early on in training as the principle inherent in reversal learning is that reversals take place. If animals show consistent biases, then their ability to reverse learning may be questioned.

As previously mentioned, the sign cows made fewer errors over successive reversals than the no-sign cows. In effect, the no-sign cows were undergoing traditional reversal learning training, while the sign cows, with the addition of the visual cue, were not. It is possible that the sign cows could have been learning a simple go-to-yellow (and not to the unmarked arm) discrimination, but their data still provide evidence that, when provided with a cue, cows can reverse responding immediately. These data support previous research demonstrating that ungulates can learn to attend to various visual cues in order to locate food, e.g., sheep (Edwards et al., 1997) and cattle (Howery et al., 2000; Kidunda & Rittenhouse, 1992; Renken et al., 2008). However, the current results contrast with those reported by Martin et al. (2006) and Sappington et al. (1997) who suggested that visual elements may increase the difficulty of reversal tasks. For example, horses in Martin et al.'s study achieved no reversals when they were required to reverse responding on the basis of either following or avoiding a light, however, this low performance may have been as a result of inadequate salience of the visual cue used. The present data suggest that the sign cows showed no difficulty in reversing responding based on the visual cue presented.

Cows were presented with two novel T-mazes in the current experiment. One maze was in a different orientation and location (T-maze 2) and the other in a different location (T-maze 3) from T-maze 1, but both were located in the same yard area. Despite the change in orientation and location within the yard, the sign cows showed no change in performance, and continued to select the correct arm of the T-maze with a high level of accuracy, showing that they had transferred learning to the new mazes. The no-sign cows

also transferred behaviour learned in T-maze 1, but made more errors compared to the sign cows (see Tables 7 and 8). Cows in Experiment 1 did not transfer learning to approach the yellow stimulus in a new location. However, stimulus presentation was altered *and* presented in a new setting in that experiment; therefore it is possible that not enough common stimuli were present in the new location to promote transfer in that case. In the current experiment, all of the same stimuli that were present in T-maze 1 were also present in T-mazes 2 and 3, which may have promoted good transfer. All T-mazes were also within the same setting. Stokes and Baer (1977) point out that generalisation may not occur if enough common stimuli that were present in the original training setting are not also present in the new setting. Comparing the results of Experiment 1 with those of the current experiment suggests that common stimuli may need to be present for cows to transfer previously learned behaviour. However, the extent to which cows can transfer learning was not fully tested here.

Cows on an AMS farm in New Zealand must learn to change previously learned behaviour in order to adjust to the requirements of the AMS. The current data show that cows can reverse a previously learned response and, if provided with a visual cue, will learn to select the arm of a T-maze (i.e., reverse responses) in which the visual cue is presented with fewer errors than cows not provided with a visual cue. The current experiment also shows that cows can learn to respond correctly in a T-maze. A choice of two directions is the minimum situation that cows face when exiting pasture and moving to the dairy. However, the size of New Zealand farms, and the subsequent distance between pasture and the dairy, means that cows must commonly learn more than two turns or sequences to reach an AMS. Cows must travel to the dairy alone on AMS farms, and so must learn to select the correct path without assistance. To do this requires some maze learning ability, as cows are essentially required to solve maze problems that can change on a daily basis. As an extension of these findings with T-mazes, Experiment 3 sought to examine cows learning in a maze of increased complexity.

Experiment 3

As previously mentioned, the large size of New Zealand farms results in cows experiencing more than one choice point as they travel to the dairy. On pasture-based AMS farms, a central race usually leads from the SU to the AMS unit and provides a direct route to the dairy with no other choice points. However, cows are faced with choice points in order to reach this race. Thus, more investigation of maze learning in cattle seems relevant to an investigation of cows using signs to travel on an AMS farm.

In the early 1900's, Psychologists assessed the learning ability of animals using mazes. Early designs were modelled on human mazes, such as at Hampton Court Palace, but designs soon reduced in simplicity as it became evident that the process of maze learning in animals was more complex than first envisaged by researchers (Keller & Schoenfeld, 1950). Early maze designs were often complex, and while animal performances in them showed evidence of learning (i.e., decreasing times to solve the maze and an increasing percentage of correct responses), Catania (1992) points out that their complexity did not offer any insights as to what was learned at a given choice point. Therefore, mazes were simplified to designs such as the T-maze, as the provision of only one choice point allowed for better analysis of what was being learned.

Early maze research also tended to focus on how an animal's inferred conscious state related to its ability to solve a maze. Pearce (1987) points out that cognitive theorists attempted to explain maze learning by proposing that as an animal moves through a maze, spatial information is used to form a cognitive map, which the animal then recalls on successive trials. Mazur (1994) says that behaviourists saw no need to explain this ability in terms of cognitive maps, rather they tended to explain maze learning in terms of responses, whereby learning occurs by developing associations between responses (turns) and the availability of food at an end goal (termed response learning). Mazes may also be learned through place learning, whereby a maze is learned by using cues outside the maze itself (Restle, 1957). Researchers such as Tolman believed that animals were place learners, and conducted experiments to show that place learning was dominant over response learning (Hergenhahn, 1982). However, Restle suggests there is a lack of clear evidence to support a claim of dominance of response over place learning, or vice versa. Instead, he argues that mazes are learned using multiple cues, and that the rate of learning is proportional to the number of relevant cues available. Hence, Restle suggests that place learning will occur in an

environment where cues external to the maze itself are available, but in an environment where external maze cues are minimised, response learning will be dominant. Thus, it is important to consider both response and place learning in maze research, as both intra and extra maze cues can influence maze learning.

The simplification of mazes led to the design of T-mazes, which, as mentioned previously, offer only one choice point at the top of the T to a right or left arm. Learning can then be measured by running time to solve the maze, which should decrease over successive trials, and the percentage of correct selections to one arm or the other, which should increase over successive trials. To show learning, the behaviour ratio should increase as the number of trials increase. T-mazes have been used to investigate a range of abilities in a variety of species. For example, T-mazes have been used to measure reversal learning in rats (North, 1950), newts and terrapins (Seidman, 1949), isopods (Thompson, 1957), paradise fish (Warren, 1960) and cats (Cronholm, Warren & Hara, 1960), and have been used to assess foraging in sheep and goats (Hosoi et al., 1995a), and preference in pigs (van Rooijen & Metz, 1987). To the authors' knowledge, only one published study, conducted by Lensink et al. (2006), has used a T-maze to measure learning in cattle. Y-mazes, which are logically the same as T-mazes without the requirement of right angle turns, have been more commonly used in research with cattle. For example, Y-mazes have featured in research used to determine preference for different handling techniques (Grandin et al., 1994; Pajor et al., 2000; 2003) and preference for food or being milked in an AMS (Prescott, Mottram & Webster, 1998b). They have also been used to measure discriminative ability (Hagen & Broom, 2003; Schaeffer & Sikes, 1971; Wieckert et al., 1966), avoidance of aversive stimuli (Arnold et al., 2008), aversive conditions (Phillips & Morris, 2001) and foraging ability (Hosoi et al., 1995a). These studies, together with the results of Experiment 2, show that cattle can learn to navigate simple mazes.

Maze designs are also able to produce more complex maze tasks. Perhaps one of the most versatile complex maze designs is the Hebb-Williams closed field maze. Designed by Hebb and Williams (1946), this maze consists of movable barriers that enable the formation of multiple maze problems that have a number of different routes leading to an end goal. An advantage of the Hebb-Williams design is that it allows for the construction of maze problems that differ in complexity. Hebb-Williams mazes can be adapted for many species, and have been used with small animals such as rats and cats (Pollard, 1961), rabbits (Livesey,

1966) and possums (Pollard & Lysons, 1967), and large animals such as horses (McCall, Potter, Friend & Ingram, 1981) and cattle (Kilgour, 1981).

Movable barriers in the Hebb-Williams maze allow for the construction of both visual or non-visual maze problems. Visual problems allow visual solution of the correct pathway at a given choice point by allowing an animal to see the next part of the correct path from the preceding choice point. Non-visual problems do not allow visual solution, so animals may have to select and move down a path in order to learn if another path is available. It has been largely found that animals show improved performance on visual problems as opposed to non-visual problems. This has been reported with cats (Pollard, 1961; Pollard, Lysons & Hughes, 1965), possums (Pollard & Lysons, 1967), rabbits (Livesey, 1966) and horses (McCall et al., 1981). Additional maze cues can also be provided in the Hebb-Williams maze by presenting contrasting walls and floors to distinguish routes, however, it is not clear whether animals make use of these extra cues. Pollard, Baldock and Lewis (1971) presented domestic hens with a Hebb-Williams maze. In their first experiment, they presented visual and non-visual problems (as described above) and showed that hens were not better at solving problems with a visual solution. In a second experiment, they added contrasting walls and floors to the maze and reported that hens made fewer errors on visual problems, suggesting that they were better at navigating the maze when the floor and walls contrasted. However, Preston, Pollard and Baldock (1969) found that contrasting walls and floors did not improve maze performance in rats, showing that rats did not use additional visual cues to solve their Hebb-Williams maze problems. Pollard et al. (1971) suggested that the degree of reliance of an animal on its visual system may be a determinant of their use of visual cues in maze situations. Therefore, it may follow that ungulates, who must forage efficiently to ensure survival, may make more use of visual cues than other species. However, what large animals such as ungulates learn in order to solve mazes, and whether they would utilise additional visual cues to do so, has not been extensively investigated.

The complexity of a maze problem can be increased by the inclusion of detours. Tasks that involve a detour require a deviation away from a direct path in order to reach the end goal (Chapuis, 1987; Candland, 1968). Animals show different abilities to solve detour problems. Detour behaviour has been shown in a variety of species, including the octopus (Schiller, 1949), monkey (Davis, 1958), chick (Regolin, Vallortigara & Zanforlin, (1995), duckling (Heaton, 1978), jumping spider (Tarsitano, 2006), horse (Wolff & Hausberger, 1996) and dog (after observing a human demonstrator) (Pongrácz, Miklósi, Vida & Csányi,

2005). Few studies have investigated maze learning in cattle, and existing research has not specifically addressed their ability to solve detour problems. Paths leading to a race and dairy (or SU when applied to pasture-based AMS) may often involve a detour. Thus, cows may be required to move away from other cows that may be visible in the goal area (the race) in order to reach the SU which has to be entered to gain access to the race (J.Jago, personal communication, 2005). On a prototypical AMS farm in New Zealand, cows that failed to solve this kind of detour task required fetching manually from pasture, which resulted in an increase in labour input. Therefore, whether or not cows can solve detours is relevant to AMS, but has not been fully investigated.

Few studies have investigated maze learning in large animals. Several studies have demonstrated maze learning in horses (Kratzer, Netherland, Pulse & Baker, 1977; Marinier & Alexander, 1994; McCall et al., 1981). For example, Kratzer, et al. (1977) showed that horses could learn a simple maze with a choice of two turns (left or right) and McCall et al. (1981) and Marinier and Alexander (1994) showed that horses could learn more complex mazes. A handful of studies have investigated complex maze learning in cattle. One of the most comprehensive studies was conducted by Kilgour (1981). He adapted a Hebb-Williams closed field maze to assess maze learning in 73 jersey cows. Cows were presented with 12 test problems, half of which were visual problems and half of which were non-visual problems. He showed that cows learned maze problems quickly, and made fewer errors on visual problems. More difficulty was shown with problems involving a route that required a move in direction away from the direct diagonal path (i.e., a detour). While this finding suggests that cows may lack detour solving ability, Kilgour generally reported excellent maze learning in cattle. This finding was later confirmed by Arave, Stewart and Walters (1992), who placed heifers in a Hebb-Williams closed-field maze and presented problems similar to those used by Kilgour.

Arave, Lamb, Arambel, Purcell and Walters (1992) examined the ability of calves to locate milk in a three turn maze. Testing was carried out over three days, in which milk was initially placed on the right side of the maze for two days, and was then placed on the left hand side of the maze on the final day of testing. Calves learned to reach the end goal over the first two days of testing, but time taken to locate the milk increased with the change to the left side of the maze on the third day. While calves showed that they could learn the maze, Arave et al. (1992) suggested calves showed poor learning ability in that they tended to continue turning right on day three when the correct response was to turn left. Given the

limited research examining maze learning in cows, it would seem that further investigations are appropriate.

The current experiment expanded on the findings of Experiment 2 and examined maze learning in cattle using a more complex maze. The aims were three-fold. One was to examine cows' maze learning in a maze slightly more complex than the single T-maze used in Experiment 2. Therefore, maze complexity was increased by using a double T-maze. This effectively increased maze difficulty by offering two choice points and four possible correct paths. As in Experiments 1 and 2, an aim was to use experimental conditions that were close to that cows would experience on a farm. Therefore, the double T-maze was constructed in the same yards as used previously. The stimuli were changed so that they resembled those that might be realistically used in a farm setting. This could be done on a real farm by painting sections of gates. Thus, the current stimuli approximated the appearance of a painted section of gate. Based on the successful use of yellow in Experiments 1 and 2, yellow plastic piping that could be positioned on to the yard fencing was used. A further aim of the experiment was to expand the findings of Experiments 1 and 2 and determine whether cows could learn to select a visual discriminative stimulus and use it to navigate a double T-maze. To assess this, two heifers were presented with a visual cue in the maze (sign heifers), and two heifers were not presented with a visual cue (no-sign heifers). Based on the results of Experiments 1 and 2, it was expected that stimulus control would be established and that the visual cues would be used by the sign heifers to navigate the maze. If so, the sign heifers should learn the double T-maze faster and make fewer errors than heifers not presented with visual cues.

Method

Subjects

Subjects were four experimentally naïve Friesian cross heifers, aged around 18 months at the start of the experiment. The heifers had limited handling experience. Housing and maintenance was the same as for previous experiments.

Apparatus

A double T-maze was formed in the same modified animal holding yards previously used. The base of the maze measured 1.5 m wide by 6 m long and the length of the arms were about 1.5 m wide by 9 m long (left arm) and 3 m wide by 9 m long (right arm). The central part of the maze that connected the arms (termed here the first choice point) was 2 m wide by 4 m long. Stimuli were constructed from yellow plastic piping (typically used for underground gas lines) with a 50 ml interior diameter. The piping was cut in half to create four 0.5 metre long half-pipes, two of which were clipped on to the fencing in the test area. The right plate of Figure 17 illustrates how the stimuli were presented. Feed bowls, rubber matting, stopwatch and data book were the same as used in previous experiments.

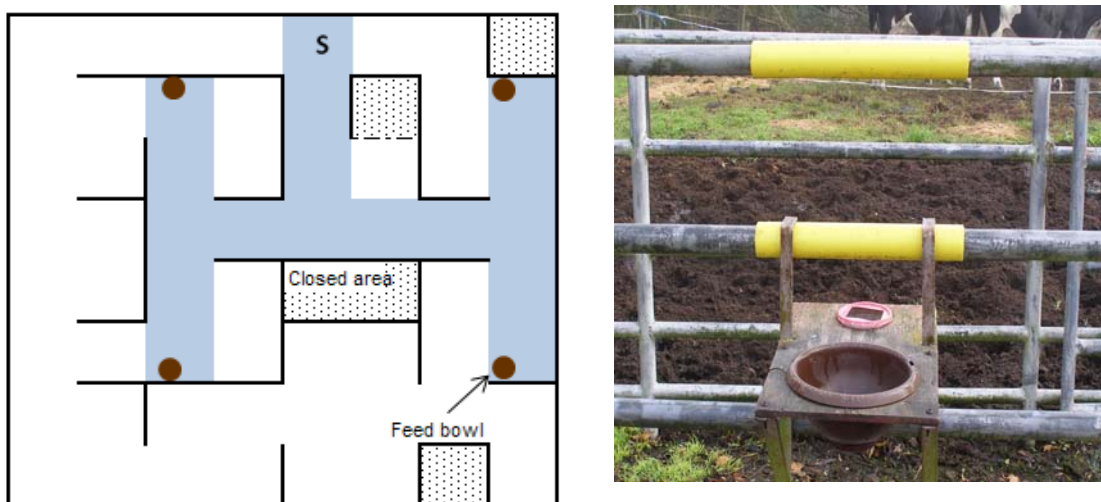


Figure 17. The double T-maze (left plate) and the yellow stimuli clipped onto the yard fences (right plate).

Procedure

Session time and duration, separating of cows into pairs and the amount of food delivered as reinforcement were the same as for previous experiments. One pair of heifers (4413 and 4406) were presented with the visual cue (termed here sign heifers) and the other pair (4411 and 4409) were never presented with the visual cue (termed here no-sign heifers). For the sign heifers, four yellow stimuli were clipped onto the yard fencing. Two stimuli were placed at the first choice point (where the first choice to go either to the left or right arm had to be made) and two were placed above a feed bowl containing food at the second choice point or end goal (see the right plate of Figure 17 for stimulus presentation). Figure 18 shows the placement of stimuli for a left-right correct trial and a right-left correct trial. For the no-sign heifers, no yellow stimuli were present in the maze. Selection of the arm marked with the yellow stimuli (sign heifers) or correct arm (no-sign heifers) was always reinforced, while selection of the unmarked arms produced no reinforcement. A non-correction procedure was used on incorrect trials, as in Experiment 2.

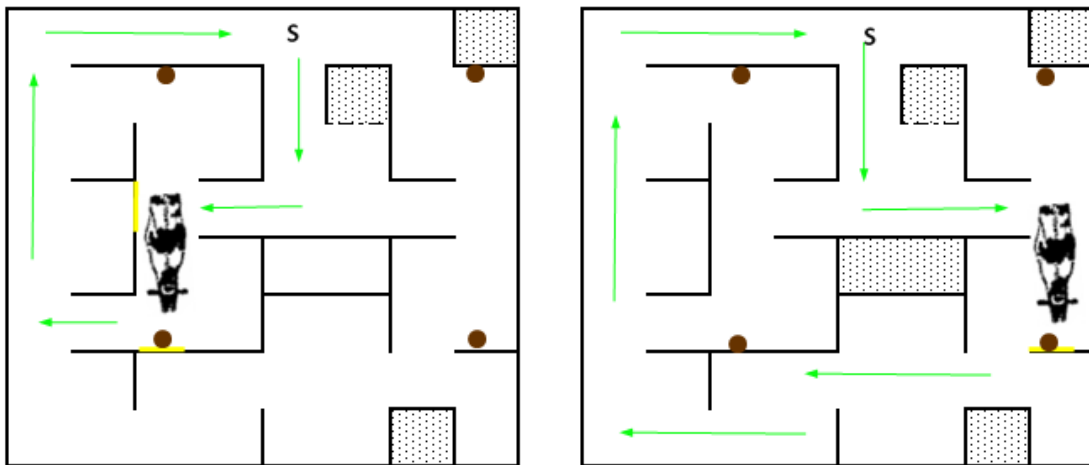


Figure 18. A right-left correct (left plate) and a left-right correct (right plate). The yellow lines indicate the position of the stimuli and the green arrows represent the correct path and the route taken back to the start of the maze for the next trial.

The general test procedures (i.e., commencement of trials, switching of stimuli in between trials and walking heifers back to the start for the next trial) and criterion were the same as those used in Experiment 2. Trial duration was timed from a point where a heifer's shoulder passed a gate at the base of the maze (about 1.5 m from the yard perimeter) until her shoulder passed another gate about 1 m from the feed bowl at the end of a right turn in the left arm (a left-right) and 1.5 m from the feed bowl at the end of a left turn in the left arm (a left-left). These gates in the right arm were 1.6 m from the feed bowl for a right-left trial and 1.3 m from the feed bowl for a right-right trial. The experimenter prevented heifers changing direction once these points had been passed.

Training. Cows were habituated to the yard area in the same manner as used in Experiments 1 and 2. However, the heifers were young and not as easily handled, so this training had to be continued for one month. Due to their unpredictable behaviour, all gates within the test area were left open during habituation to prevent situations where animals could not move forward. At the end of one month the heifers' flight distances from an experimenter had reduced to values which did not seem likely to disrupt handling for maze learning to a great extent. Therefore, test trials commenced.

Test procedure. Despite extensive training, the heifers were still generally difficult to handle and it was unclear how many trials could be completed in a session. Therefore, the first session used 20 trials, and as these were completed within a sensible time (30-40 min), 25 trials were conducted for all subsequent sessions. Time constraints resulting from the initial extended training time and the fact that heifers were due back on-farm for mating, resulted in only 11 sessions (270 trials) being completed. Three problem changes were presented (left-right (LR), right-left (RL), left-right (LR)). Left-left (LL) and right-right (RR) problems, which involved a forward path followed by backwards turn to the end goal, were never presented.

Results

Performance was analysed by calculating the percentage of correct responses for each half of the double T-maze, as shown in Figure 19. The dashed vertical lines indicate problem changes from LR, RL, and back to LR again. The left panel shows the percentage of correct responses at the point where the first response left or right had to be made (i.e., the first choice point). Accuracy on the first half of the maze was generally above 75 % correct for all heifers across the first two problem changes. There was an initial decrease in responding to below this level for 4413, 4406 and 4409 on the third problem change LR. The right panel shows performance on the second half of the T-maze, for which data were calculated as the percentage of the number of trials where there was a correct first turn at the first choice point (i.e., not a percentage of all trials). The graphs show that when a correct response was made at the first choice point, the following response at the second choice point was also generally correct, at between 90-100 %. No visible difference in accuracy was shown between the sign and no-sign heifers.

Total trial duration (i.e., across both choice points) was analysed by calculating the average time to complete correct and incorrect trials, and is shown in Figure 20. The dashed vertical lines indicate problem changes. Trial duration was initially long for 4413 (sign heifer) and 4411 (no-sign heifer), with more time taken to complete incorrect trials. All heifers generally took longer to complete incorrect trials than correct trials. Similar patterns of responding can be seen between the two groups of heifers; one sign heifer (4406) and one no-sign heifer (4409) tended to have shorter trial durations, while trial duration for the remaining heifers (4413 and 4411) varied, especially when the correct direction was changed.

Figure 21 is a graphical representation of the paths selected by heifers in the double T-maze. Each diagram represents a plan of the double T-maze, and illustrates the number of trials made left-right, on which a left first selection was followed by a right selection, and right-left, on which a right first selection was followed by a left selection. The lines represent each path taken, and the width of these lines is proportional to the total number of trials in which that particular path was chosen (indicated at S). The numbers beside each line indicate the number of times a path was chosen.

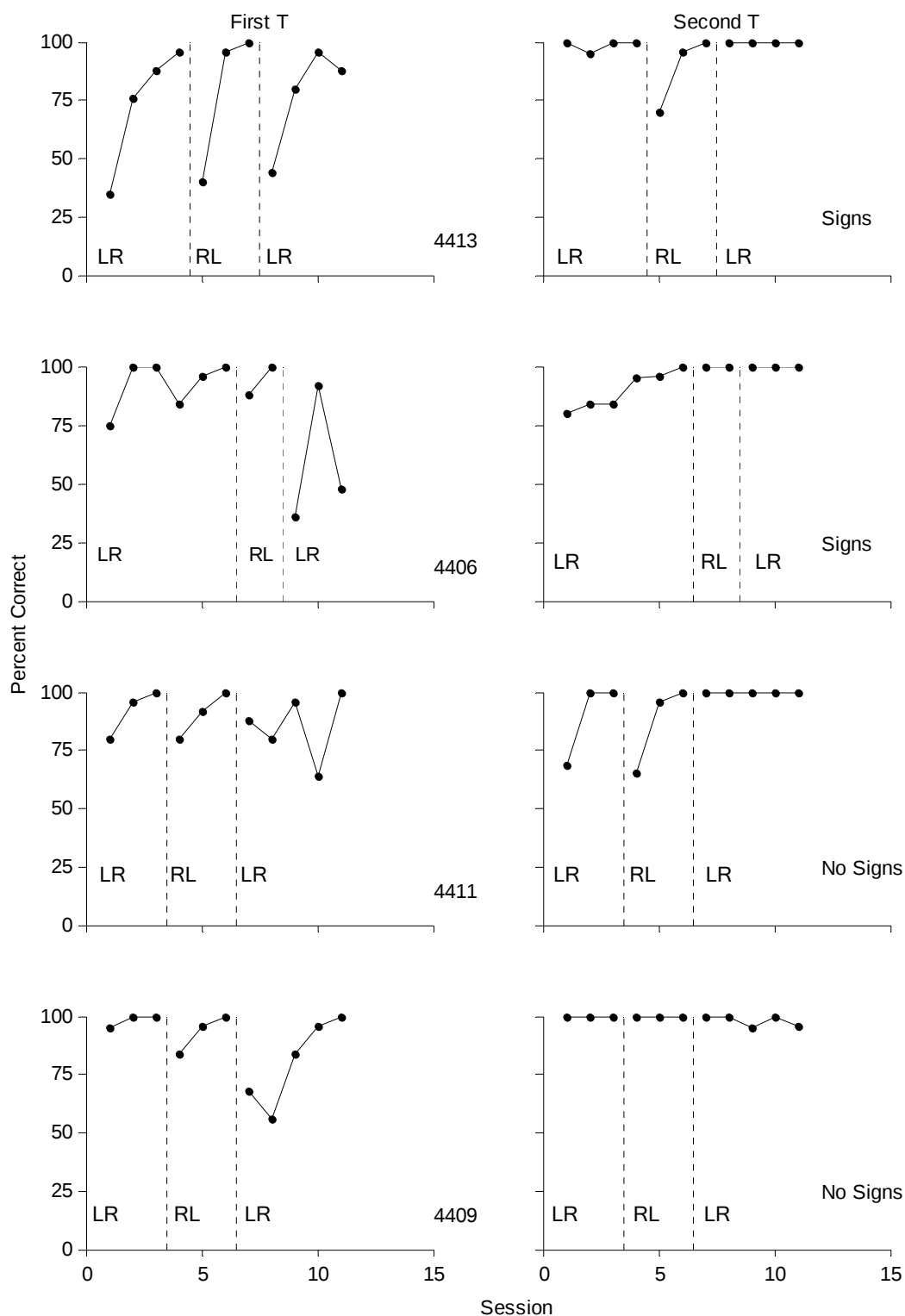


Figure 19. Percent correct at the first choice point (left panel) and the second choice point (right panel) as a percentage of the number of trials where there was a correct response at the first choice point in the double T-maze.

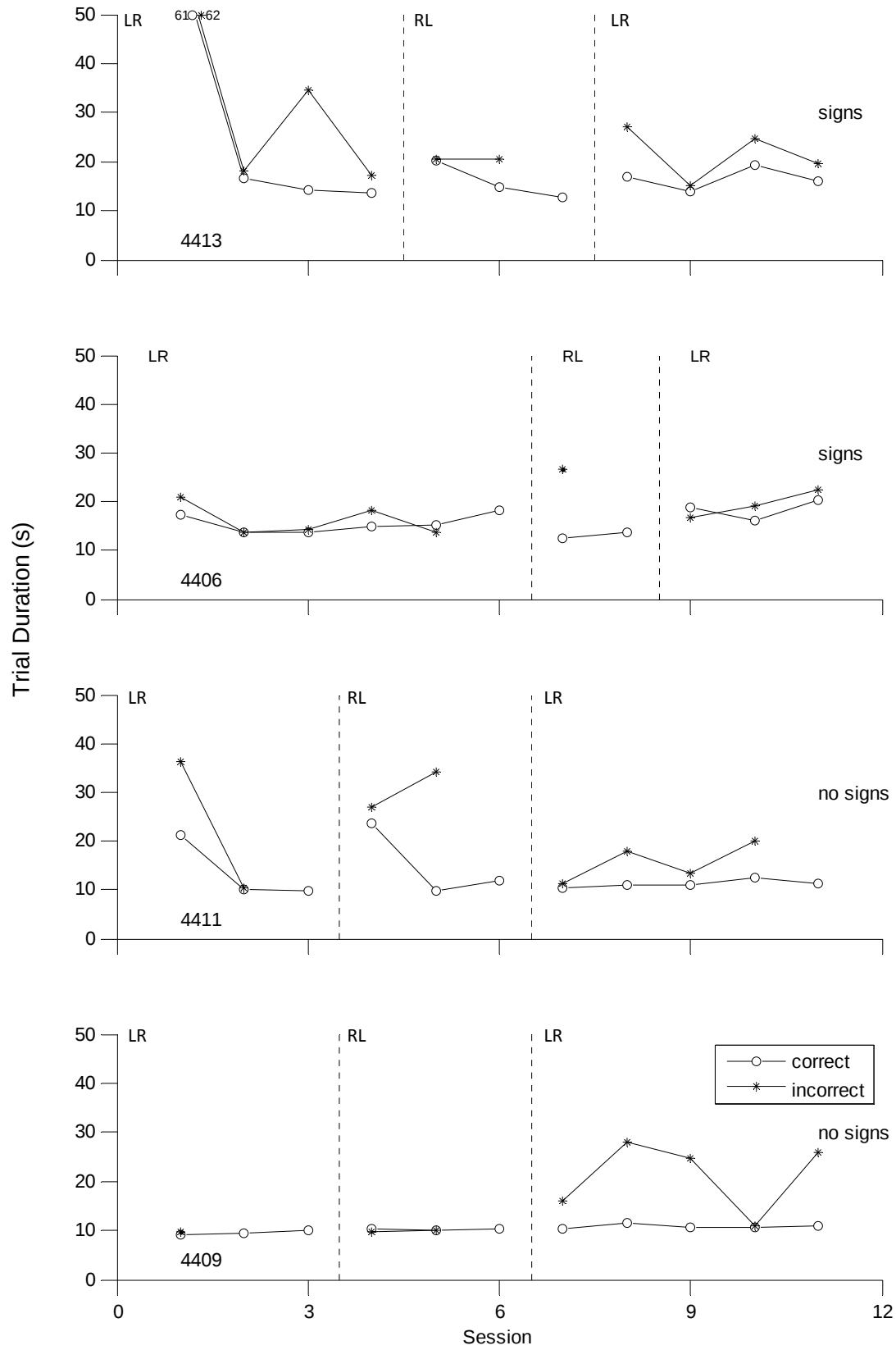


Figure 20. Average trial duration for each heifer across problem changes LR, RL and LR.

The narrow lines deviating from the main maze path indicate paths that were errors and the dashed lines show paths that were never selected (as indicated by the number zero). Figure 21 shows that heifers were highly accurate at learning to find the end goal in the double T-maze, regardless of whether the correct path was LR or RL. Heifers completed the same number of trials (270), but more left-right trials were completed than right-left trials.

Table 9 shows the total number of incorrect paths selected when the correct path was LR and RL. Selection of an incorrect path was counted as one error, as if an incorrect path was selected at the first choice point; the selection made at the second choice point was also inevitably an error. Table 9 shows that when the correct path was LR, more errors were made RL. The no-sign heifers made fewer errors than the sign heifers on this problem. When the correct path was RL, more errors were made LR by all heifers. Two heifers from each group (4406 (sign heifer) and 4409 (no-sign heifer)) made fewer errors than the remaining heifers on this problem. More errors were made when the correct path was LR, but more trials were completed with this path.

Table 10 shows the total number of errors made within the first session after a change in the direction of the correct path had been made (i.e., LR to RL and RL to LR). Heifer 4413 (sign heifer) made fewer errors on the second direction change from RL to LR, but 4406 (sign heifer) made more errors on the second direction change from RL to LR. Heifer 4411 made fewer errors changing from RL to LR and 4409 made more errors on the same direction change. The no-sign heifers (4411 and 4409) made fewer total errors when the correct path changed direction than the sign heifers.

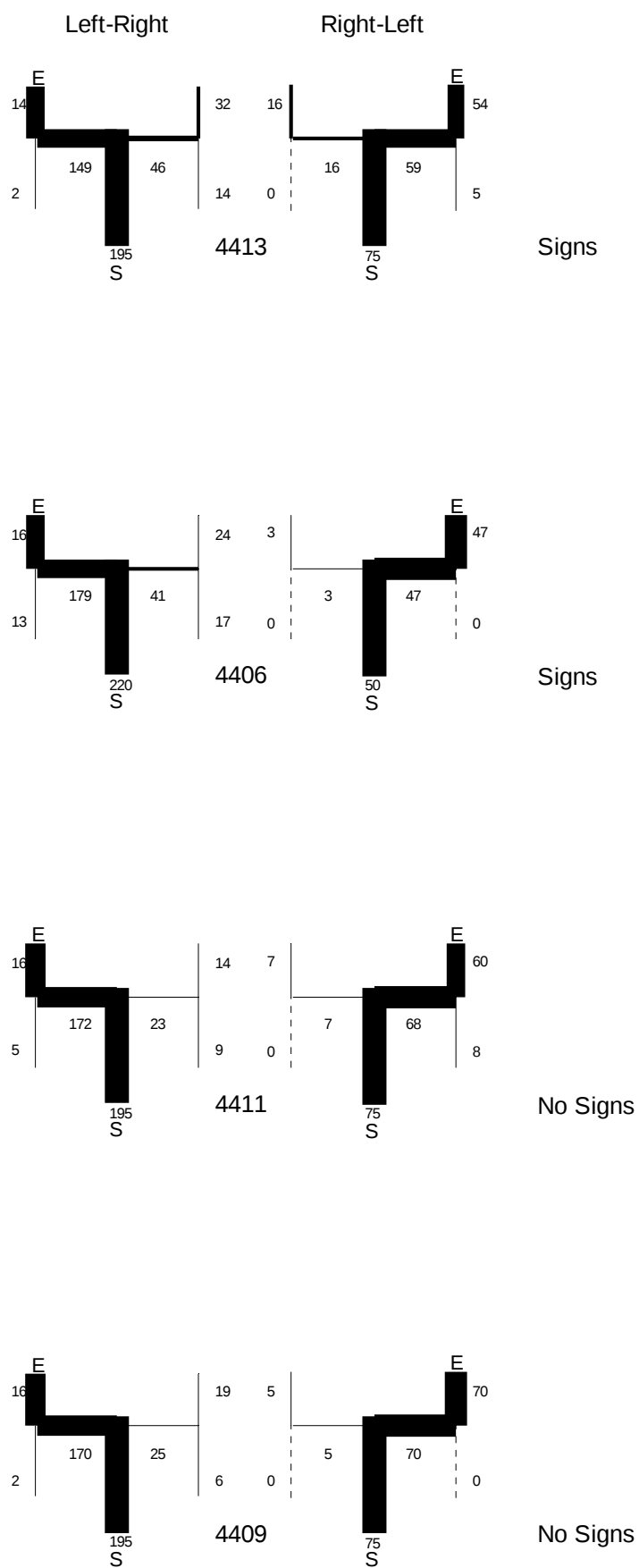


Figure 21. Correct paths (bold lines) and errors made (narrow lines) left-right (left) and right-left (right) by each heifer in the double T-maze.

Table 9.

The total number of trials and total and proportion of incorrect paths (errors) selected when the correct path was left-right (LR) (left) and right-left (RL) (right).

Left-right correct								Right-left correct							
Sign/ no-sign	Heifer	Total trials	Errors LL	Errors RL	Errors RR	Total errors	Proportion errors	Sign/ no-sign	Heifer	Total trials	Errors LL	Errors LR	Errors RR	Total errors	Proportion errors
Sign	4413	195	2	32	14	48	0.25	Sign	4413	75	0	16	5	21	0.28
Sign	4406	220	13	24	17	54	0.25	Sign	4406	50	0	3	0	3	0.06
No-sign	4411	195	5	14	9	28	0.14	No-sign	4411	75	0	7	8	15	0.20
No-sign	4409	195	2	19	6	27	0.14	No-sign	4409	75	0	5	0	5	0.07

Table 10.

Total errors made within the first session after a change in direction of the correct path from LR to RL and RL to LR.

Sign/no-sign	Heifer	Errors LR to RL	Errors RL to LR
Sign	4413	19	14
Sign	4406	3	16
No-sign	4411	12	3
No-sign	4409	4	8

Discussion

The aims of the current experiment were only partly met. Heifers learned to locate food in the double T-maze, confirming that cows can learn this more complex maze. However, the results did not show that the sign heifers were more accurate or made fewer errors than the no-sign heifers in solving these mazes. As there was no difference in performance between the two groups, it appears that the provision of visual cues was irrelevant in solving the maze. The explanation of these results is not clear given the findings of Experiment 2. It is clear that the visual cues were not controlling behaviour, so sufficient stimulus control had not been established. It is possible that the current results may have been due to the change in stimulus from Experiment 2, or that this maze learning task was solved using other stimuli. These possibilities will be discussed further.

A double T-maze is essentially a combination of two single T-mazes, so on the basis of the results shown in Experiment 2, it was expected that the heifers would show accurate and fast learning in this maze. This was confirmed, with correct responding at over 80 %. This performance is comparable to previous research using simple mazes (i.e., Hagen & Broom, 2003; Schaeffer & Sikes, 1977; Wieckert et al. 1966). Time constraints in the current study allowed for tests of learning on maze problems with only forward directions (i.e., RL and LR), so problems requiring reversals in direction (i.e., RR and LL) were not presented. Therefore, these data do not bear on how behaviour may have been affected if heifers had been required to complete RR and LL turns.

The current results support general findings comparing the performance of heifers and cows. Pajor et al. (2000) reported that heifers were more difficult to handle, which was also shown in the current experiment. In Experiments 1 and 2, cows underwent five days of habituation before starting each experiment, whereas in the current experiment, it was necessary to extend the habituation/training time to one month. Despite the extended training time, the heifers were still not as calm in the experimental setting as the older animals. It has been reported that young cattle learn faster than older animals (Kovalčik & Kovalčik, 1986). Older animals did not complete a double T-maze in the current experiment, so a direct comparison could not be made. However, the heifers did learn the double T-maze quickly, completing three direction changes in 11 sessions and did not appear to use signs to do this.

There was no difference between the number of incorrect paths selected (errors) made by heifers presented with visual cues and heifers not presented with visual cues. Thus, the signs did not aid heifers in this task. These results do not support the results of Experiment 2, which showed that when presented with a visual cue, cows learned to reverse responding with more accuracy and made fewer errors in a single T-maze than cows not presented with a visual cue.

One possibility for these results is that the visual stimuli used were not prominent enough for discrimination, resulting in a failure to establish adequate stimulus control. In an attempt to approximate a more realistic farm-like setting, the stimuli used were intended to resemble the look of painted gates. The half-pipes lay flat against the yard fencing, so it is possible that this presentation resulted in the stimuli not standing out visually, although research strongly suggests that yellow is one colour that cattle can discriminate from grey. If salience was an issue, sign heifers may not have been attending to these visual cues, resulting in both groups essentially facing the same maze problem (i.e., the presence of visual cues was irrelevant to maze learning in this case). So it may be that, had more prominent cues been used, the sign heifers would have been faster and more accurate at learning the maze.

A second possibility is that the task simply took the same amount of time to learn for both groups of heifers, i.e., the visual cues were salient enough for discrimination, but it was as easy for sign heifers to learn the maze with visual cues as it was for the no-sign heifers to learn the maze without visual cues. Sign heifers may have learned the task through stimulus-approach (i.e., approach yellow where it is presented) and the no-sign heifers may have learned the task through response-selection (i.e., learn to turn at each choice point), or both groups of heifers may have learned the maze using response-selection. If the maze was learned through response-selection, an increase in the number of initial errors would be expected when the maze problem changed from LR to RL. One heifer from the sign group (4413) made 19 errors with this direction change, while one heifer from the no-sign group (4411) made 12 errors (see Table 10). The remaining heifers, one from the sign group (4406) and one from the no-sign group (4409) made few errors on this direction change. Therefore, it is difficult to determine whether response-selection or stimulus-approach was occurring in this case.

It is also possible that the maze was learned by place learning, i.e., heifers learned the correct maze sequence by using cues external to the maze itself. The maze

was located outdoors, therefore a number of external stimuli were present (e.g., trees, a car park, an old dairy building). These cues were distinctive and stable enough to provide additional information to both groups of heifers and may have been exerting more control than the artificial visual cues provided. This explanation implies that the combination of internal and external cues was equally effective for both groups and that the additional sign stimuli may not have added enough of an extra maze cue to make a difference. As with response-selection, if place learning was occurring, an increase in the number of errors would also be expected with the change in direction of the maze problem, as the new path would have to be re-learned using different external cues. It is possible that this occurred for two heifers (4413 and 4411), but the remaining heifers (4406 and 4409) made few errors when the correct path changed, which suggests that place learning was not occurring for these animals.

As Restle (1957) argues, both external (to the animal and also, if available, to the maze) and internal cues come to control maze behaviour, and as such, the likelihood of one or the other type of learning occurring (either response or place) is equal to the proportion of relevant cues available (e.g., increased external cues will result in maze learning by place, and a lack of external cues will result in response learning). Either process could have been occurring in the current experiment. A rotation of the double T-maze, or an exclusion of the external cues, may have identified which process was occurring, however, further investigation was not possible within the timeframe available with these animals.

As previously mentioned, cows may experience more than one choice point as they travel to the dairy. The results of the current experiment showed that heifers were able to solve a maze with two choice points and four choices of direction. However, no difference in performance was seen between the sign and no-sign heifers, showing that the maze was equally solvable with and without visual cues. Response or place learning may have been occurring, but which one of these processes (or whether both were) could not be determined. In an attempt to approximate how stimuli may be presented on a farm, stimuli were designed to resemble the look of a painted section of gate. However, it is possible that these stimuli were not salient enough. In addition, Experiment 2 used a reversal learning task, which in itself may have trained cows to use the visual cue. A reversal learning task was not conducted in the current experiment, which may have also affected performance.

The current experiment shows the potential for cows to learn more complex mazes. Therefore, Experiment 4 aimed to expand the current findings by examining whether cows could learn a more complex problem than a double T-maze.

Experiment 4

To the authors' knowledge, Experiments 2 and 3 are the only research investigating maze learning in cows when additional visual cues are provided within the maze itself. Experiment 2 showed that cows learned to select the arm of a T-maze (i.e., reverse responses) in which a visual cue was presented with fewer errors than cows not provided with a visual cue. Experiment 3 showed that heifers learned a double T-maze, but it was not clear whether the visual cues presented in Experiment 3 were being used or whether other cues were controlling behaviour. Experiment 3 did not train a reversal task, whereas Experiment 2 explicitly taught reversal learning, which may have made the visual cue more salient. The signs used as stimuli in Experiment 3 were considered to be more practical than those used in Experiment 2 as they approximated the look of painted gates, so it was thought that re-testing these stimuli was appropriate, but in this case the following experiment began training with a reversal learning task. Therefore, Experiment 4 sought to investigate whether or not cows could learn to use the same signs as used in Experiment 3 to solve more complex maze problems when reversal learning was included.

Signs were present in all conditions of the experiment, as the main aim was to determine whether or not cows could learn to solve more complex mazes with the use of such additional visual cues. Experiment 2 showed that a single T-maze was a relatively practical method of training cows to select the correct arm of a maze when it was signalled by a yellow sign. Experiment 2 also showed that cows had learned to use the sign over a period of reversal learning. Therefore, cows in the current experiment were trained to select the arm of a T-maze associated with yellow signs and food, followed by reversals. To promote stimulus control, all cows were then required to reverse responding as the yellow stimuli and correct arm were quasi-randomly presented to each arm of the maze. Another aim of the experiment was to examine the use of signs in more complex mazes. Therefore, following the single T-maze, yellow stimuli were used to signal the correct arm and access to food in a double T-maze. Finally, eight complex maze problems were presented in the same yard area previously used. Each maze problem contained a different sequence of turns and used the whole yard area as this was a realistic setting that approximated what cows actually experience on farms in New Zealand. Also to ensure that the setting was as similar as possible to the situation in which it might be applied, maze problems were not enclosed and were left as open passageways. Signs were initially present in these more complex maze problems, but were

not presented in all maze problems to allow an examination of whether or not cows were better at solving mazes with the use of signs. Based on the results of Experiments 1 and 2, it was expected that cows would learn to select the correct path that was signalled by the yellow signs to gain access to food. Therefore, it was expected that cows would be better at completing complex mazes problems with signs present.

Method

Subjects

Four Friesian cross dairy cows participated in this experiment. Three cows (3112, 3420 and 3978) were experimentally naïve and were approximately three years old at the start of the experiment, and one cow (7841), was approximately five years old and had had previous experience from Experiment 1. Housing and maintenance were the same as for previous experiments.

Apparatus

The various mazes used the total area (17 m long by 6 m wide) of the previously used yards. Several different mazes were created: a single T-maze (see Experiment 2 for dimensions), a double T-maze (base: 3 m wide by 7 m long, central junction: 2 m wide by 4 m long, right arm: 3 m wide by 9 m long and left arm: 1 m wide by 9 m long (see Figure 22)) and eight complex mazes that traversed most of the yard area (see Figures 23-24). Stimuli used were the same as for Experiment 3 and all other equipment were the same as for previous experiments.

Procedure

Session time and duration, separating of cows into pairs and the amount of food delivered as reinforcement were the same as for previous experiments. A non-correction procedure was also in place for all conditions. The experiment consisted of six conditions; Conditions 1-3 used a single T-maze, Conditions 4 and 5 used a double T-maze, and Condition 6 involved the presentation of eight complex maze problems. All cows were presented with visual cues in all conditions of the experiment.

Training. Cows were habituated to the yard area over five days in the same manner as used previously.

Condition 1. The yellow signs were positioned in one arm of a single T-maze and cows learned to select that arm using the procedure used in Experiment 2. One addition was made to the general procedure as it was noted during initial sessions that cows occasionally watched the experimenter change stimuli in between trials. Therefore, all

actions denoting a change in side were performed in between trials to prevent cows from selecting an arm solely on the basis of observing the change being made in that side. This required that the experimenter walk from arm to arm in between every trial irrespective of the need to change stimuli.

Condition 2. The procedure was identical to Condition 1 with the exception that sessions were extended to include 26 trials. The yellow stimuli were reversed to the opposite arm within each session if, of the first 13 trials, the last 10 trials were correct. The last 10 trials of the session also had to be correct in order to reverse the following session. This criterion was later reduced as it was noted that cows often made mistakes as a reaction to sudden noises from the adjoining building or the appearance of people walking across the car park adjacent to the test area. Therefore, cows had to make correct selections in the last five trials of the first 13 trials before reversing mid-session, and in the last five trials of the session before reversing the following session.

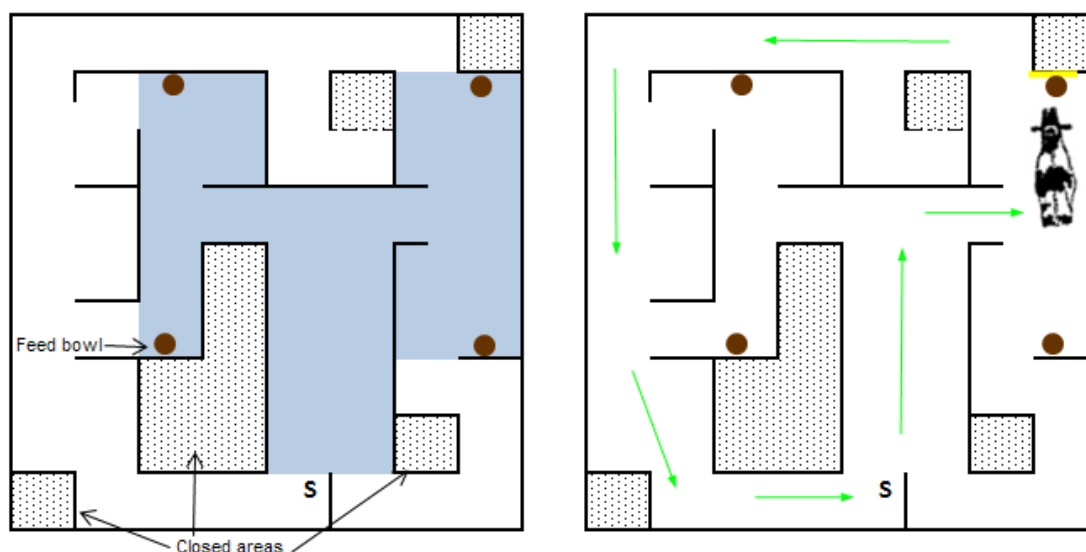
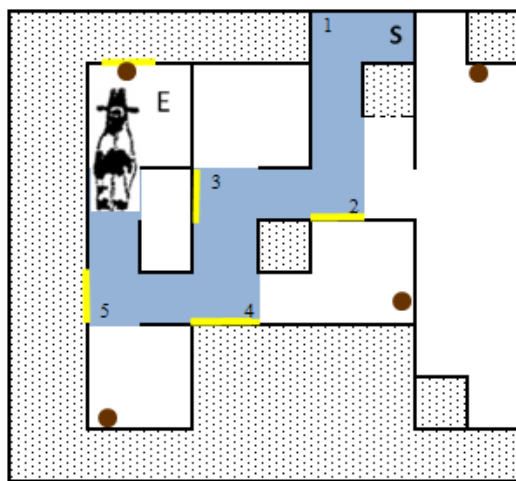


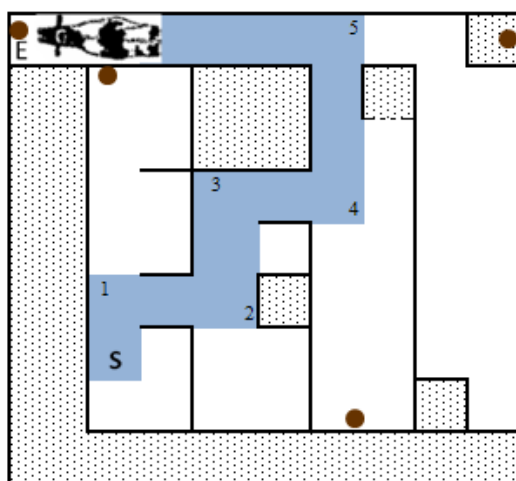
Figure 22. Plan of the double T-maze (left plate), where S indicates the start of the maze and the shaded area marks the base and arms of the T. The yellow bar (right plate) indicates the position of the yellow stimuli for a right-left correct trial and the green arrows represent the path taken to select an arm and return to the start point for the next trial.



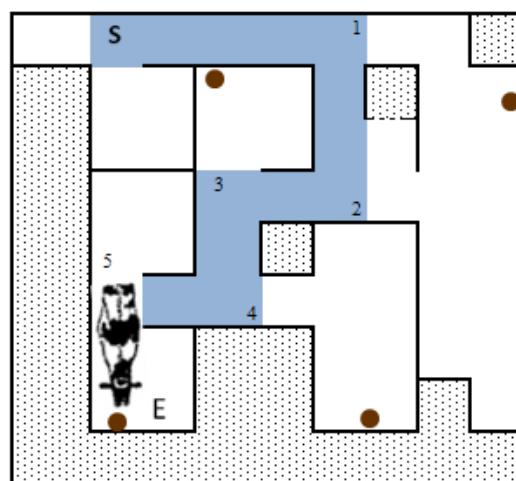
Figure 23. Maze plans of maze problems presented with signs (S=start E=end goal). The shaded area represents the correct path to the end goal, the yellow bars represent the position of the stimuli, and the numbers represent a correct turn.



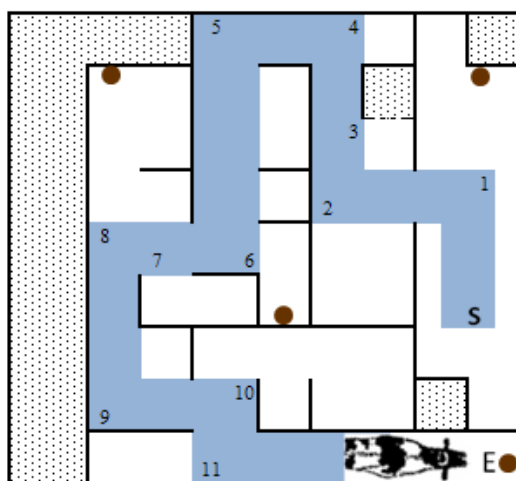
MAZE E2 with signs



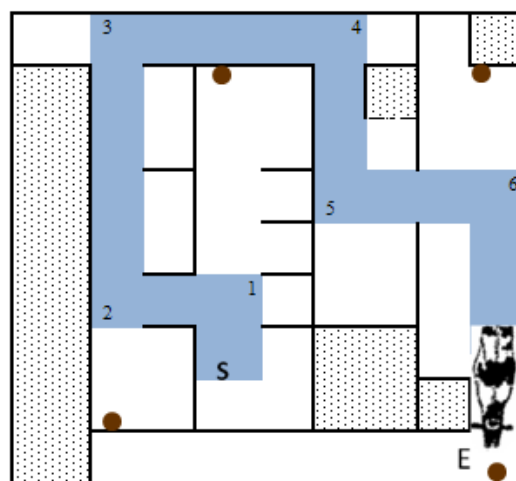
Maze A without signs



Maze B without signs



Maze D1 without signs



Maze F without signs

Figure 24. Maze E2 presented with signs (top left) and the maze problems that were presented without signs (Mazes A, B, D and F) (S=start E=end goal). The shaded area represents the correct path to the end goal, and the numbers represent a correct turn.

Condition 3. Condition 3 used an identical procedure to the previous condition, with the exception that the yellow stimuli signalling the correct arm were positioned in the arms of the maze according to a quasi-random series with no more than three consecutive presentations to the same arm. Table 11 shows the total number of sessions and trials completed in each condition in the single T-maze.

Condition 4. Condition 4 involved the presentation of visual cues in a double T-maze. The start point of the maze was rotated 180 degrees from the double T-maze used in Experiment 3 (see Figure 22). The general procedure was the same as used for Experiment 3, with the exception that 24 trials were conducted per session. The first 12 trials started with either a left or right correct at the first choice point, followed by six random trials to the left and right arms at the second choice point. Hence the 24 trials had 12 trials with a left first turn and 12 trials with a right first turn and equal numbers of left and right second turns (e.g., 12 random LR and LL trials followed by 12 random RL and RR trials).

Table 11.

The number of sessions and trials completed by each cow in each condition in the single T-maze.

Sign/no-sign	Cow	Condition 1		Condition 2		Condition 3	
		Sessions	Trials	Sessions	Trials	Sessions	Trials
Sign	7841	5	125	7	182	6	156
Sign	3112	7	175	7	182	3	78
Sign	3420	11	270	7	182	4	104
Sign	3978	8	200	6	156	4	104

Trial duration was timed from a start point where the cow's shoulder passed a gate at the base of the maze (about 1.5 m from the yard perimeter) and was stopped when her shoulder passed another gate about 1.8 m from the feed bowl at the end of a right turn in the left arm (a left-right) and 1.9 m from the feed bowl at the end of a left turn in the left arm (a left-left). These gates were 1.8 m from the feed bowl for a right-left trial and 1.6 m from the feed bowl for a right-right trial in the right arm. Cows were prevented from changing direction by the experimenter once these points had been passed as per previous experiments.

Condition 5. The procedure was identical to Condition 4, with the exception that the yellow stimuli signalling the correct arm were quasi-randomly presented across all four directions of the double T-maze (RL, RR, LR, LL). Table 12 shows the total number of sessions and trials completed in each condition in the double T-maze.

Table 12.

The number of sessions and trials completed by each cow in each condition in the double T-maze.

Sign/no-sign	Cow	Condition 4		Condition 5	
		Sessions	Trials	Sessions	Trials
Sign	7841	10	240	3	72
Sign	3112	6	144	3	72
Sign	3420	5	120	6	144
Sign	3978	4	96	3	72

Condition 6. Condition 6 involved the presentation of eight complex maze problems. Figures 23 and 24 show the layout of each maze problem. The shaded path represents the correct path to reach the end goal and the yellow bars represent the placement of the yellow stimuli. The total number of turns required to reach the end goal were derived by counting the number of correct turns needed to solve the maze, but also

included every point where there was an option to turn off the correct path (for example, turn 1 in Maze C). Each turn is numbered in Figures 23-24. A single yellow sign was placed at positions that were visible from the preceding correct turns and no visual cues (yellow stimuli) were present in the mazes presented without signs.

In addition to the correct path, between three and six (depending on the maze) incorrect paths were also open so they could be selected and moved into. The feed bowl at the end goal was the only bowl to contain food, but three other feed bowls were placed at the end of incorrect paths. A small plastic container was placed behind all feed bowls and held a small portion of food to control for the possibility that discriminations were being made with the aid of olfactory cues. Occasionally a correct path contained a forced turn with no choice of direction, termed here 'no-choice turns'. These turns were forced because there was no other option for animals to take. The number of correct turns to reach the end goal, no-choice turns and total number of turns per maze problem are shown in Table 13. The position of each no-choice turn is also indicated.

Table 13.

The correct number of turns to reach the end goal, the number and position of no-choice turns, and the total number of turns per maze problem.

Maze	Sign/No-sign	Number of correct turns	Number of no-choice turns	No-choice turn position	Total number of turns
A	Sign/No-sign	4	1	Turn 3	5
B	Sign	4	1	Turn 2	5
B (no sign)	No-sign	5	0	N/A	5
C	Sign	7	2	Turns 2 + 6	9
D1	Sign/No-sign	8	3	Turns 4, 5 + 9	11
D2	Sign	6	3	Turns 4, 5 + 9	9
E	Sign/No-sign	6	3	Turns 6, 7 + 8	9
E2	Sign/No-sign	5	0	N/A	5
F	No-sign	5	1	Turn 4	6

All cows completed eight maze problems. Both 3112 and 3978 completed mazes in the same order. However, 3978 completed a simplified version of maze D1 (maze D2) instead of completing a second session in D1 because 3112 had failed to solve maze D1 on her second session. These cows never experienced maze F, as this maze was designed after 3112 and 3978 had finished the experiment. Both 7841 and 3420 completed the same maze problems, but in a different order. These cows were presented with maze D2 instead of maze D1 (based on the performance of the first two cows (3112 and 3978)). The order in which maze problems were presented is shown in Table 14. Cows completed multiple trials over one session per maze problem; with the exception of 3420, who completed two sessions with problem C because she had not reached the criterion of 10 consecutive correct trials in her first session. It was expected that she would complete this maze based on the performance of the other cows, so another session was conducted. Each session continued until the criterion (10 consecutive correct trials) was achieved or until session duration had reached one hour, at which point the session was ended. Sessions were also ended if, after 15 min, cows had not moved from the start point or any other choice point in the maze.

At the start of each session, a cow was drafted from the stand-off paddock. An experimenter moved her through the yards to the start area via the most direct route so that she could not experience other paths before starting. The experimenter remained in the start area to record all path selections. Trial duration was recorded from the release point to the end goal. All correct trials gave access to food, but selection of an incorrect path never resulted in food. If an incorrect path was selected, an error was recorded and the trial was ended. Cows were then walked back to the start using the most direct route. Cows were not allowed to take any other routes back to the start once an incorrect selection had been made to prevent them from learning other paths or the correct path while returning to start the next trial. Food was replaced and food particles were brushed away from the tops and sides of the feed bowl in between trials.

Cows 3112 and 3978 were the first pair to progress to Condition 6. For the first four maze problems completed by these cows (problems A, B, C and D1), presentation of yellow signs was alternated. For example, Maze A was presented with signs, but signs were removed in Maze B the following session. However, alternation of sign presentation and removal affected the behaviour of these cows, therefore, the remaining cows (3420

and 7841) completed their first five maze problems with signs present before signs were removed for the last three mazes presented.

Table 14.

Maze order, the number of sessions and trials completed and whether or not the criterion was reached for each maze problem.

Cow number	Maze order	Sign/No-sign	Total sessions	Total Total	Criterion reached
7841	B	Sign	1	12	Yes
	D2	Sign	1	18	Yes
	E	Sign	1	13	Yes
	A	Sign	1	14	Yes
	C	Sign	1	22	Yes
	E2	No-sign	1	7	No
	A	No-sign	1	23	Yes
	F	No-sign	1	26	Yes
3112	A	Sign	1	15	Yes
	B	No-sign	1	3	No
	C	Sign	1	14	Yes
	D1	No-sign	1	8	No
	E	Sign	1	7	No
	B	Sign	1	11	Yes
	D1	Sign	1	5	No
	E2	Sign	1	11	Yes
3420	B	Sign	1	19	Yes
	D2	Sign	1	20	Yes
	A	Sign	1	30	Yes
	C	Sign	2	34	Yes
	E	Sign	1	17	Yes
	A	No-sign	1	16	Yes
	F	No-sign	1	6	No
	E2	No-sign	1	18	No
3978	A	Sign	1	13	Yes
	B	No-sign	1	15	No
	C	Sign	1	23	Yes
	D1	No-sign	1	11	No
	E	Sign	1	10	No
	B	Sign	1	11	Yes
	D2	Sign	1	18	Yes
	E2	Sign	1	12	Yes

Results

Performance was analysed by calculating the percentage of correct responses across Conditions 1-3 (single T-maze) and 4-5 (double T-maze), as shown in the left panel of Figure 25. The dashed vertical lines indicate changes in condition. Initially, 7841 was accurate at selecting the correct arm, with responding at around 75 %. While accuracy for the remaining cows was initially lower than this (around 25-60 %), correct responding soon increased to above 75 %. A high level of accuracy was then maintained at or above 75 % across Condition 1, in which cows learned to select one arm of the maze and Condition 2, where a reversal of correct responses was required mid-session. At the start of Condition 3, in which visual cues and the correct arm were quasi-randomly presented across both arms of the T-maze, 7841 and 3420 showed an initial decrease in accuracy, at between 50-70 %. Accuracy for these cows improved after one or two sessions to around 90 %. Both 3112 and 3978 showed no decrement in performance due to the condition change, with correct responding remaining high at between 90-100 %.

All cows showed a slight decrease in correct responding with the introduction of the double T-maze (Condition 4), but accuracy soon improved to between 90-100 % after the initial session. Performance did not change when visual cues signalling the correct arm were quasi-randomly presented across all options of the double T-maze (Condition 5), with all cows continuing to respond between 90 and 100 % correct during this condition.

The right panel of Figure 25 shows the average trial duration across Conditions 1-3 and 4-5. Trial duration was analysed by calculating the average time to respond on correct and incorrect trials. Cows 3112 and 3420 were slow to complete both correct and incorrect trials at the start of Condition 1, but trial duration then decreased to around 10 seconds across the remainder of Condition 1 and was maintained across Conditions 2-3. Response times were similar on correct and incorrect trials for all cows. Trial duration increased with the introduction of the double T-maze in Conditions 4 and 5 for all cows with the exception of 3978, for which trial duration increased only slightly from the previous conditions.

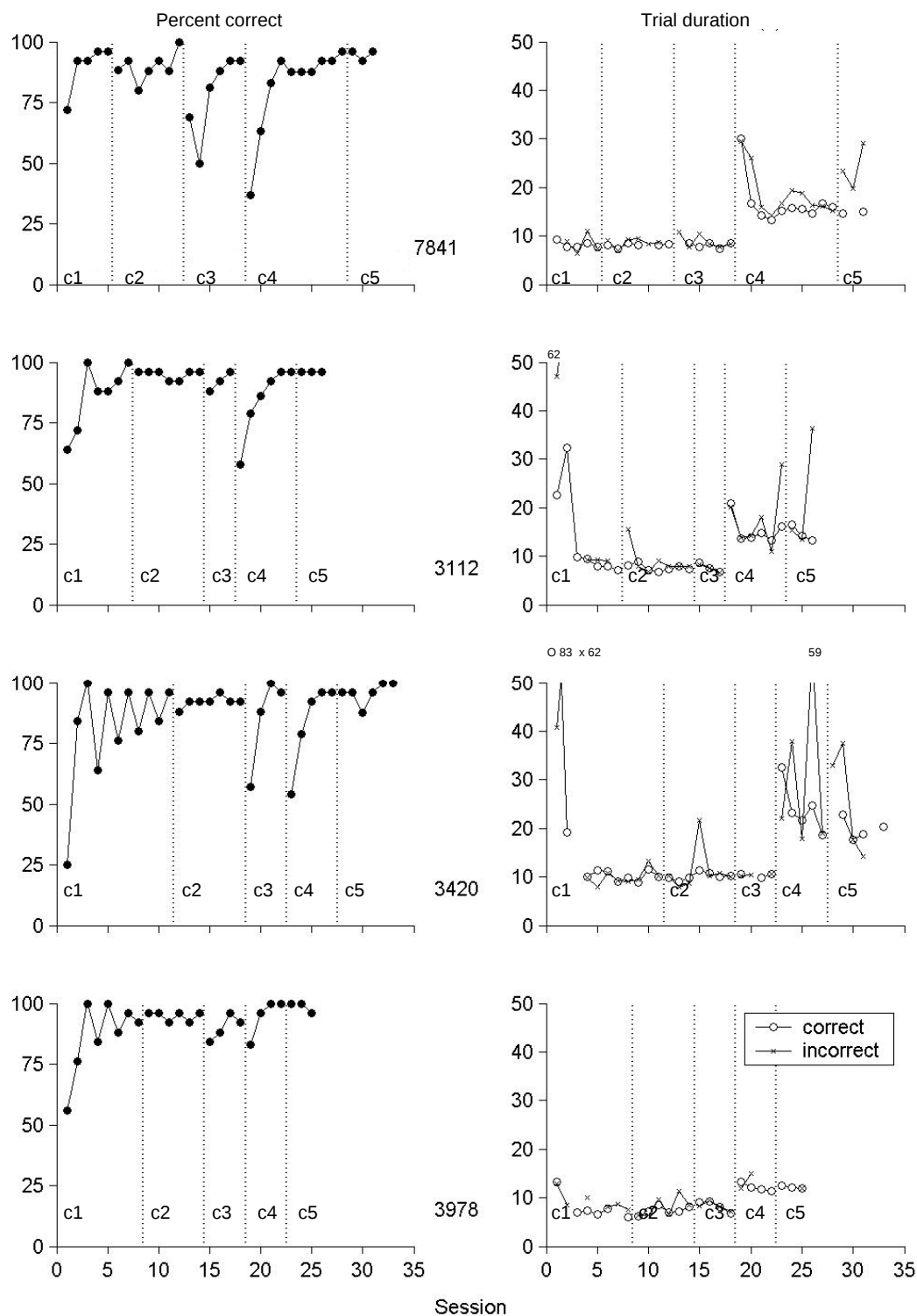


Figure 25. Percent correct (left panel) and trial duration (right panel) for each cow in Conditions 1-3 (single T-maze) and Conditions 4-5 (double T-maze).

The left panel of Figure 26 shows the number of initial errors made by each cow for every successive reversal that occurred (i.e., all reversals were counted) during Conditions 1 and 2. The dashed vertical lines indicate changes in condition. All cows, with the exception of 3420, were selecting the correct arm of the maze within 5 trials after a reversal during Condition 1. Performance improved across Condition 2, with all cows generally selecting the correct arm within zero or one trials after a reversal. Data were also analysed by calculating the total number of errors made across successive reversals (right panel of Figure 26). A rapid decrease in total errors made per reversal can be seen for all cows across Condition 1. Few errors per reversal were maintained by all cows during Condition 2.

Figure 27 shows the paths selected by each cow during Condition 3, in which the yellow stimuli signalling a correct arm were quasi-randomly presented. Each graph represents a plan of the single T-maze. Within each maze plan, line widths represent the proportion of the total number of trials that path was selected (indicated at the start point of the maze (S)), i.e., the width of each line represents the number of times the cow selected that path, and is proportional to the number of trials in which that particular path was chosen. The numbers beside each line indicate the number of times that path was chosen within the total session. The relatively few incorrect responses are indicated by the narrow lines deviating from the main maze path. All cows were accurate at selecting the correct arm of the maze when the position of the yellow stimuli was reversed. Fewer errors were made by 3112 and 3978. More errors tended to be made to the left arm when the end goal was located in the right arm.

Figure 28 illustrates the paths selected by each cow in the double T-maze. The graphs represent a plan of the double T-maze used, and the number of trials completed each direction (left-right, left-left, right-left and right-right) (shown in each column) for each cow (shown in each row). Data are presented in the same manner as described for Figure 21 (of Experiment 3). Figure 28 shows that cows were accurate at learning to solve the double T-maze, regardless of the location of the end goal. More errors were made when the correct path required a reversal in direction (i.e., LL and RR), and fewer errors were made with paths that involved a forwards direction (i.e., RL and LR).

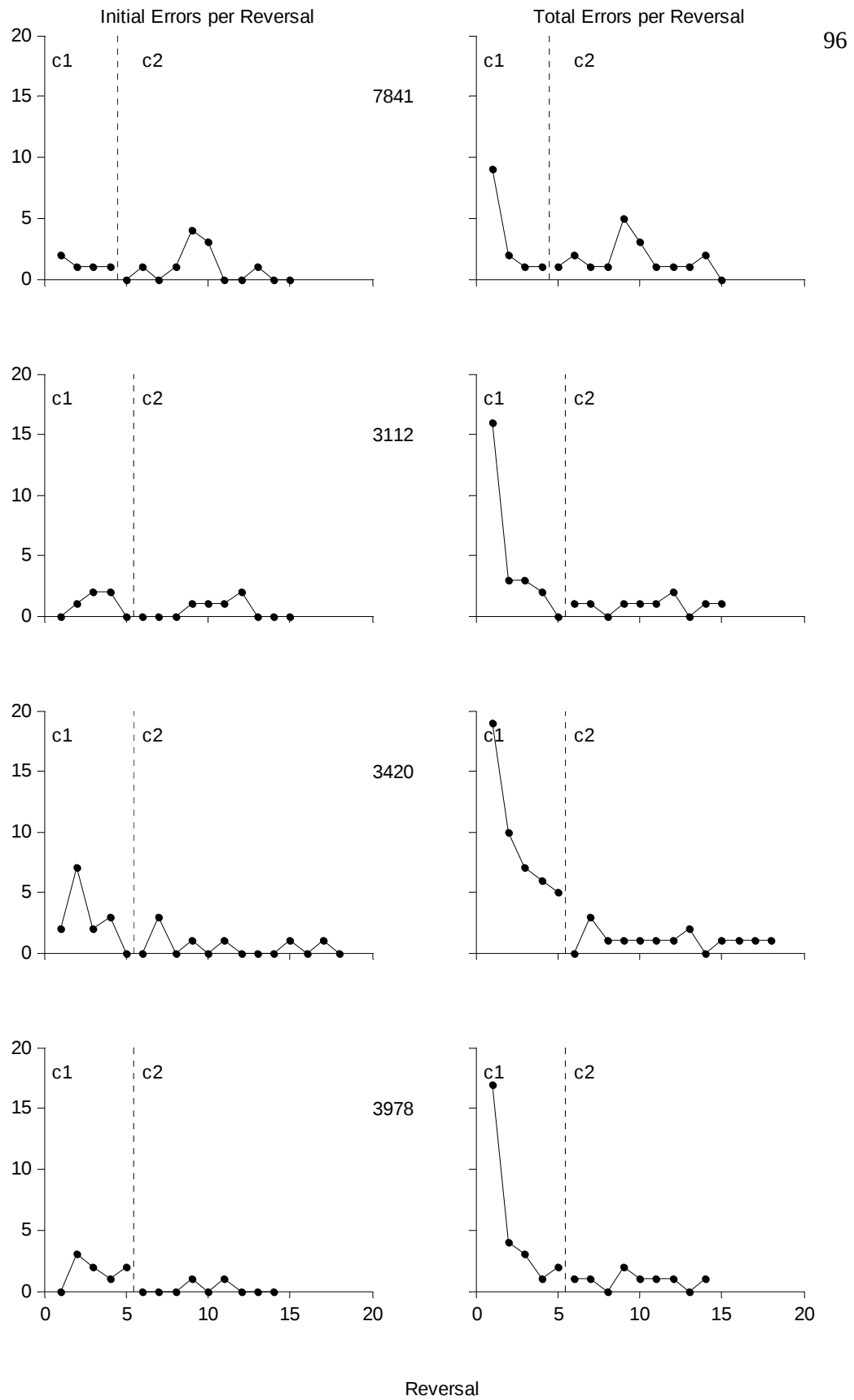


Figure 26. Initial errors per reversal (left panel) and total errors per reversal (right panel) by each cow in Conditions 1 and 2 (single T-maze).

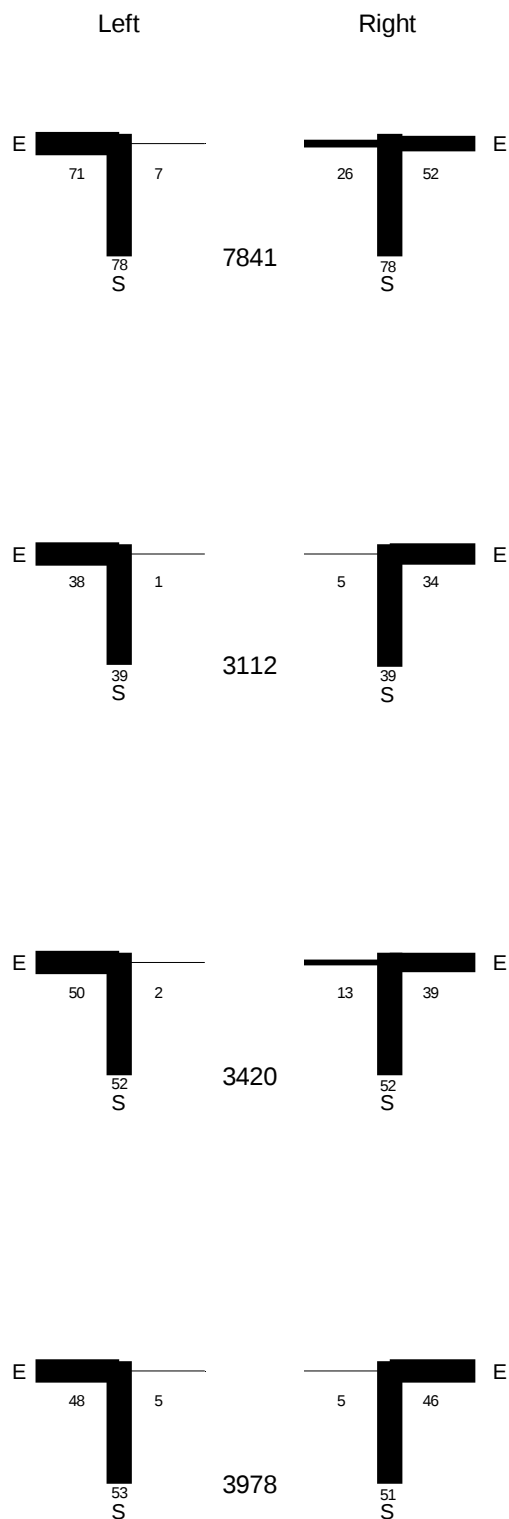


Figure 27. Correct paths (bold lines) and incorrect paths (narrow lines) selected by each cow in Condition 3 of the single T-maze.

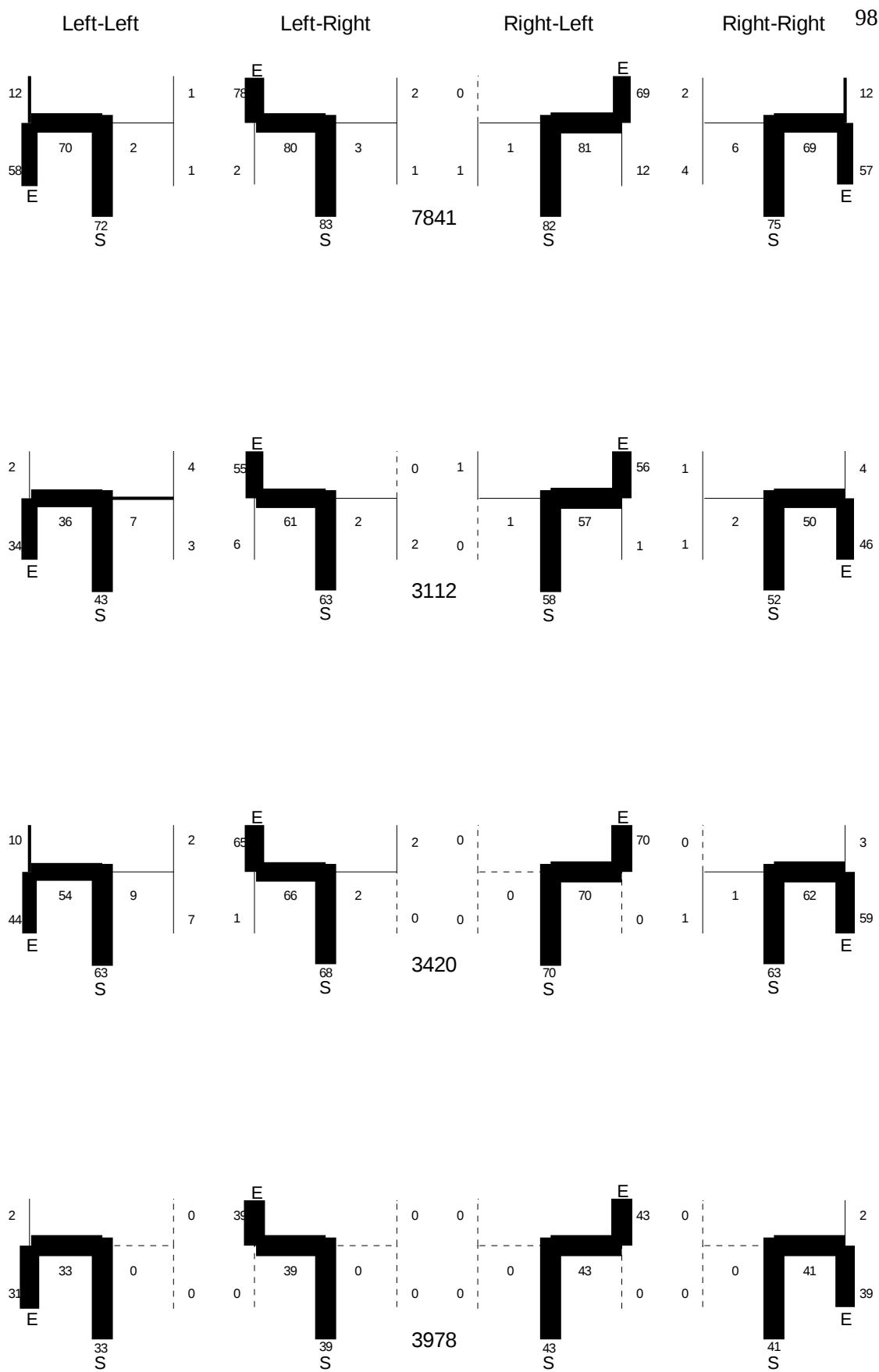


Figure 28. Correct paths (bold lines) and incorrect paths (narrow lines) selected by each cow in the double T-maze.

Table 15 shows the total incorrect paths selected (errors made) when the correct paths were LL, LR, RL and RR. When the correct path was LL, more errors were made LR by 7841 and 3420. Both 3112 and 3978 made few errors. When the correct path was LR, 3978 made no errors, while 7841, 3112 and 3420 made 5, 8 and 3 errors respectively. More errors occurred LL. All cows, with the exception of 7841, made few or zero errors when the correct path was RL. When the correct path was RR, more errors were seen RL, with 7841 making 12 errors. The remaining cows made less than 5 errors to the other paths in the maze.

Figures 29-31 represent the paths selected in the eight complex maze problems presented. Data were calculated and are presented as described for Figure 21 (Experiment 3). The asterisks represent a no-choice turn where no choice of direction was available. Where no graph is presented, a cow did not experience a maze problem (see Table 14 for maze order). Figure 29 shows the data for Maze A (with and without signs), B (with and without signs) and C (with signs). The thick bold lines in Figure 29 show that all cows learned to select the correct path to solve Mazes A, B and C when signs were present. Both 7841 and 3420 correctly solved Maze A when signs were removed, however, these cows had learned this maze with signs three sessions earlier (see Table 14 for maze order). Both 3112 and 3978 failed to complete Maze B without signs. Cow 3112 ceased responding after three trials, and 3978 never reached the end goal after 15 attempts. Both sessions for these cows were terminated when session duration exceeded 15 minutes with no movement in the maze. Both cows solved Maze B when signs were reinstated several sessions later.

Figure 30 shows the data for Maze D1 (without and with signs) and Maze D2 (with signs). Both 3112 and 3978 failed to solve Maze D1 when signs were removed. No correct responses were made out of 19 trials (100 % errors) for both cows. Cow 3112 also failed to complete Maze B two sessions later when signs were reinstated. Maze D2 with signs was completed and solved correctly by 7841, 3420 and 3978.

Figure 31 shows the data for Maze E (with signs), Maze E2 (with and without signs) and Maze F (without signs). Maze E was presented to all cows, but was correctly solved only by 7841 and 3420. Cows 3112 and 3978 failed to complete this maze, although they both reached the end goal on one and two trials respectively. However, both these cows completed Maze E2 with signs. No cow solved Maze E2 and Maze F

Table 15.

The cow number, total trials, and the total and proportion of errors made when the correct path was left-left, left-right, right-left and right-right.

Left-left correct							Left-right correct					
Cow	Total trials	Errors LR	Errors RL	Errors RR	Total errors	Proportion errors	Total trials	Errors LL	Errors RL	Errors RR	Total errors	Proportion errors
7841	72	12	1	1	14	0.19	83	2	2	1	5	0.06
3112	43	2	4	3	9	0.21	63	6	0	2	8	0.13
3420	63	10	2	7	19	0.30	68	1	2	0	3	0.04
3978	33	2	0	0	2	0.06	39	0	0	0	0	0.00
Right-left correct							Right-right correct					
Cow	Total trials	Errors LL	Errors LR	Errors RR	Total errors	Proportion errors	Total trials	Errors LL	Errors LR	Errors RL	Total errors	Proportion errors
7841	82	1	0	12	13	0.16	75	4	2	12	18	0.24
3112	58	0	1	1	2	0.03	52	1	1	4	6	0.12
3420	70	0	0	0	0	0.00	63	1	0	3	4	0.06
3978	43	0	0	0	0	0.00	41	0	0	2	2	0.05

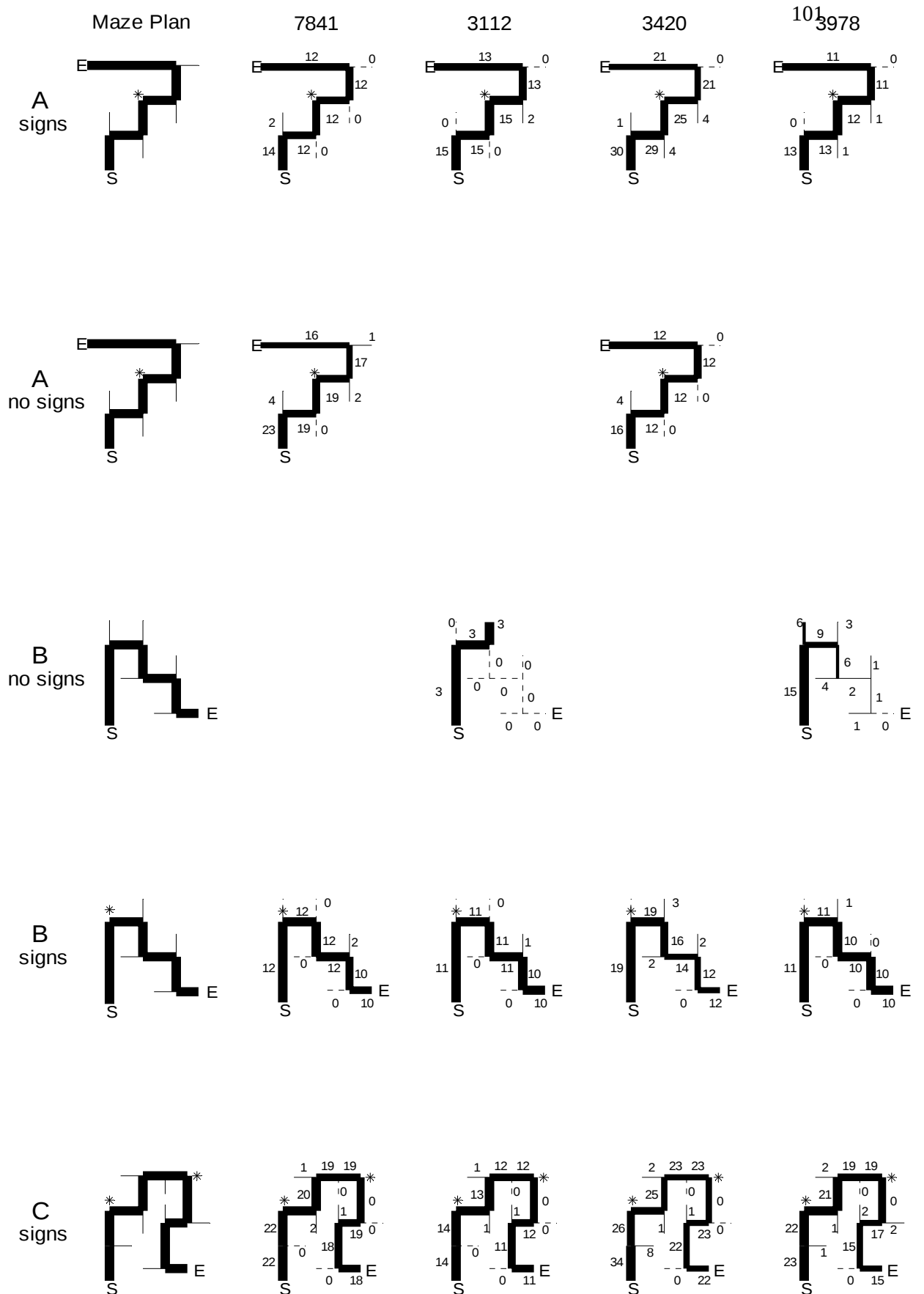


Figure 29. Maze plans (left) and correct paths (bold lines) and incorrect paths (narrow lines) for each cow on maze problems A, B and C (right) (S=start, E=end).

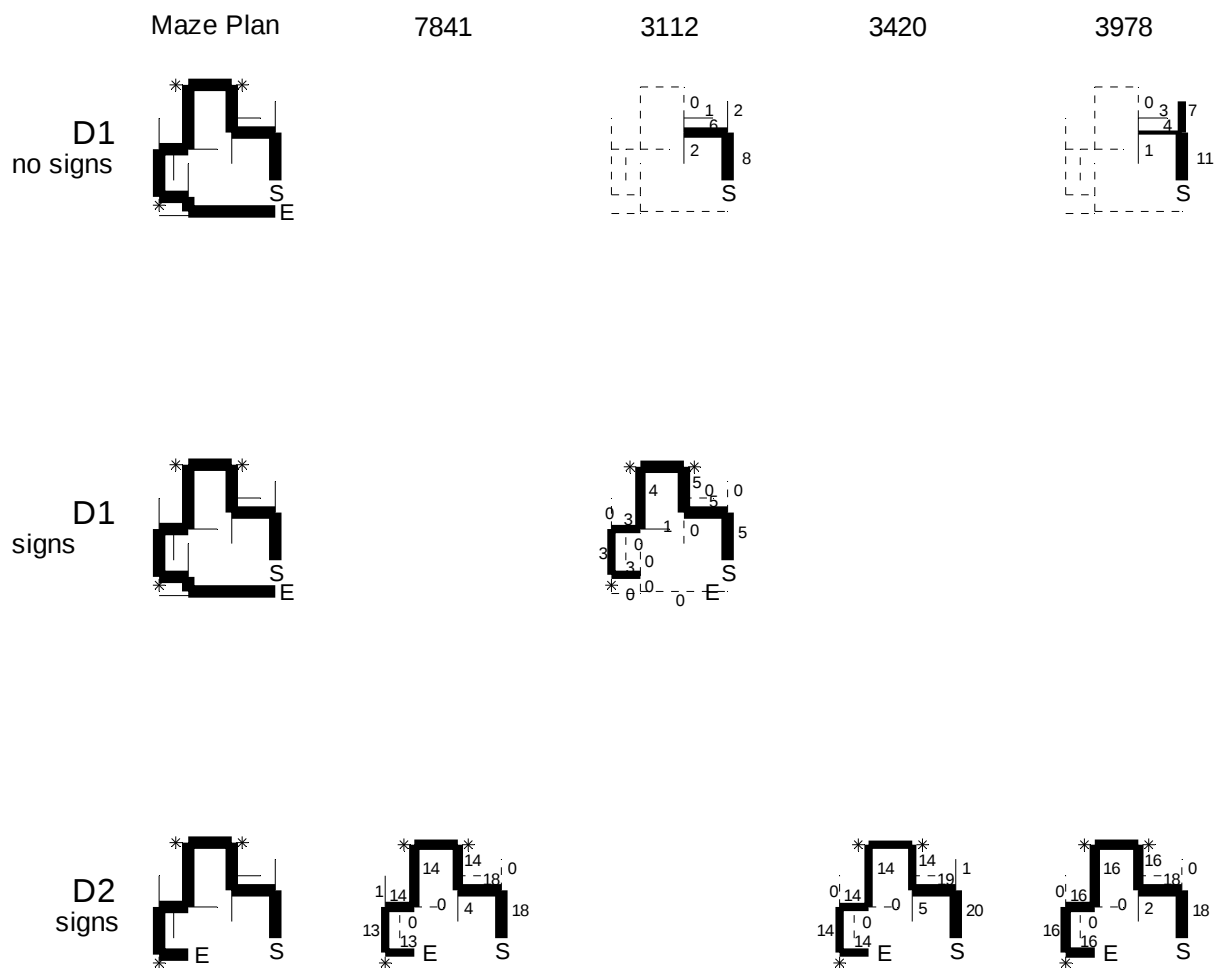


Figure 30. Maze plans (left) and correct paths (bold lines) and incorrect paths (narrow lines) for each cow on maze problems D1 and D2 (right) (S=start, E=end).

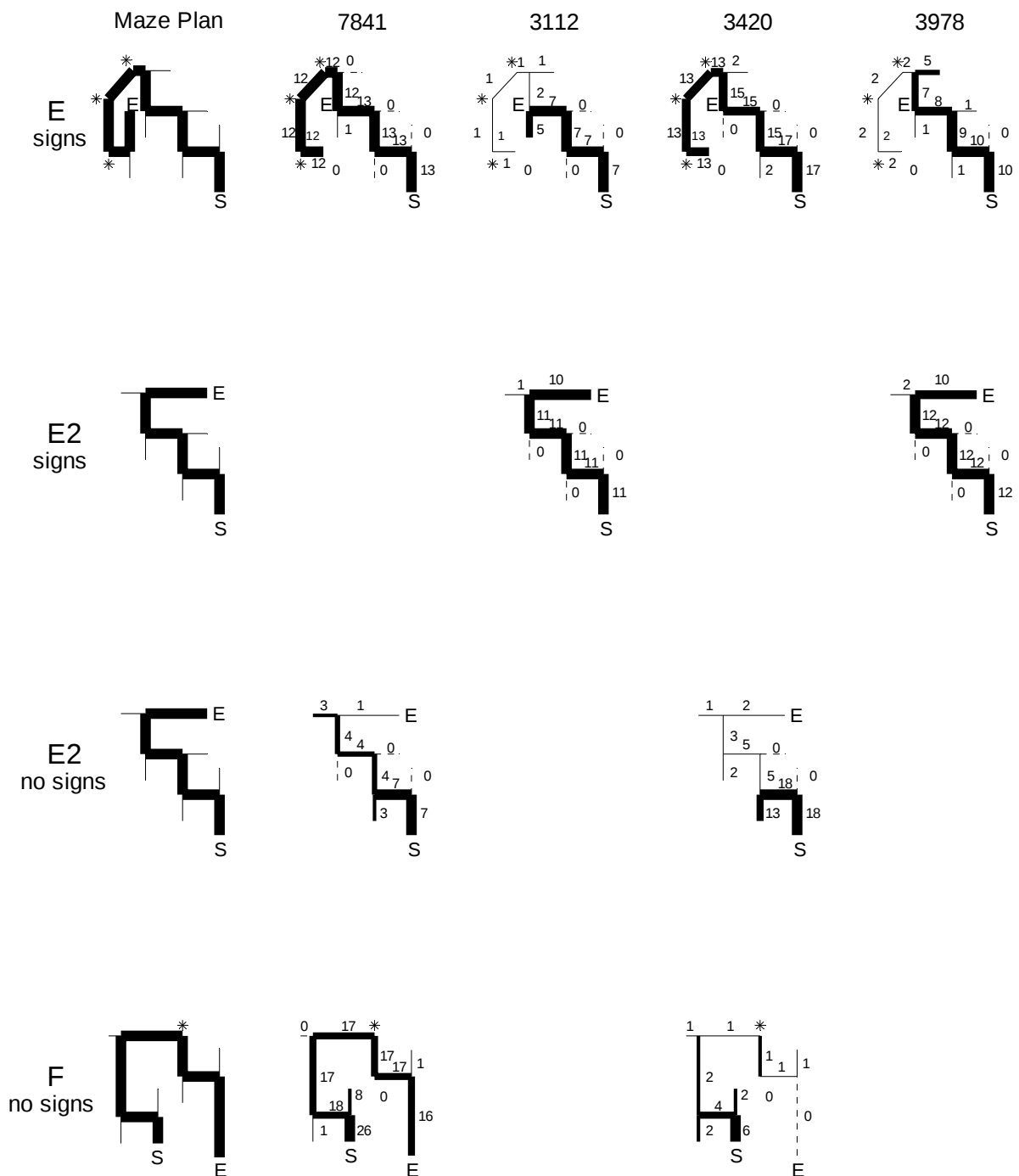


Figure 31. Maze plans (left) and correct paths (bold lines) and incorrect paths (narrow lines) for each cow on maze problems E, E2 and F (right) (S=start, E=end).

when signs were removed, with the exception of 7841, who completed Maze F despite no signs being present.

Table 16 shows the total number of trials and the proportion of errors made by each cow on each maze problem. Also shown is the number of the first correct trial within the session after the introduction of a new maze problem. Cow 7841 made more errors in the maze problems in which signs had been removed and also took more trials to select the correct path in these mazes. Both 3112 and 3978 never selected the correct path (i.e., they made 100 % errors) in Mazes B and D1 (both cows) and showed an increase in the number of incorrect paths selected in Maze E (both cows) and D1 (3112) despite signs being reinstated. Cow 3420 made more errors than the other cows in maze problems presented with signs, but more errors were made in Mazes F and E2 when signs were removed. Of the maze problems presented with signs, cows selected the correct path on the first trial on 4 out of 22 occasions and on the second trial on 9 out of 22 occasions. Of the maze problems presented without signs, the correct path was selected on the first trial on one out of 10 occasions.

Table 16.

The total number of trials and the total number and proportion of errors made by each cow. Also shown is the trial number of the first correct trial within the session for each new maze problem.

Cow	Maze problem	Condition	Total Trials	Total correct trials	Total errors	Proportion errors	Number of the first correct trial
7841	B	Sign	12	10	2	0.17	3
	D2	Sign	18	13	5	0.28	2
	E	Sign	13	12	1	0.08	1
	A	Sign	14	12	2	0.14	1
	C	Sign	22	18	4	0.18	4
	E2	No-sign	7	1	6	0.86	3
	A	No-sign	23	16	7	0.30	6
	F	No-sign	26	16	10	0.38	4
3112	A	Sign	15	13	2	0.13	1
	B	No-sign	3	0	3	1.00	0
	C	Sign	14	11	3	0.21	2
	D1	No-sign	8	0	8	1.00	0
	E	Sign	7	1	6	0.86	4
	B	Sign	11	10	1	0.09	2
	D1	Sign	5	0	5	1.00	0
	E2	Sign	11	10	1	0.09	2
3420	B	Sign	19	12	7	0.37	2
	D2	Sign	20	14	6	0.30	5
	A	Sign	30	21	9	0.30	2
	C	Sign	34	22	12	0.35	4
	E	Sign	17	13	4	0.24	3
	A	No-sign	16	12	4	0.25	1
	F	No-sign	6	0	6	1.00	0
	E2	No-sign	18	2	16	0.89	2
3978	A	Sign	13	11	2	0.15	1
	B	No-sign	15	0	15	1.00	0
	C	Sign	23	15	8	0.35	6
	D1	No-sign	11	0	11	1.00	0
	E	Sign	10	2	8	0.80	2
	B	Sign	11	10	1	0.09	2
	D2	Sign	18	16	2	0.11	2
	E2	Sign	12	10	2	0.17	3

Discussion

These data show that, after the inclusion of a period of reversal learning, cows learned to use visual cues to solve both simple and complex maze problems using the same stimuli as used in Experiment 3.

Cows performed well in the single T-maze, as also shown in Experiment 2. A decrease in the number of errors made over successive reversals was seen, showing that cows could learn the reversal task. Correct responding remained high even when visual cues and the correct arm were quasi-randomly reversed within session. All cows in the current experiment were presented with visual cues in the single T-maze, and the accuracy achieved suggests that cows were responding to the visual cues presented (as in Experiment 2).

Cows also learned to solve the double T-maze, with some cows achieving 100 % selections of the correct path. These data confirm that cows can learn this task and respond with no errors, as has also been reported elsewhere (i.e., Hagen & Broom, 2003). This experiment investigated more path changes than Experiment 3 and showed that more errors were made when the correct path required a turn deviating from the forward path (i.e., LL and RR). Tasks that involve such deviations to reach an end goal are referred to as detour problems. As previously mentioned, many species can solve detours, e.g., octopus (Schiller, 1949), monkey (Davis, 1957), chick (Regolin et al., 1995), jumping spider (Tarsitano, 2006), horse (Wolff & Hausberger, 1996), duckling (Heaton, 1978) and dog (Pongrácz et al., 2005), but few studies have addressed detour solving by cattle. Kilgour (1981) reported that more difficulty was shown by cattle when solving Hebb-Williams maze problems that involved a correct path that deviated from a direct diagonal route, suggesting that cows may not easily learn to solve detours. In the current experiment, cows clearly learned to reach the end goal despite a reversal in direction, although the RR and LL problems required only a minor detour.

The data also suggest that visual cues were controlling behaviour in the double T-maze. Cows were accurate in selecting the correct path to solve the maze, achieving 90-100 % correct and achieved errorless sessions (two cows) during Condition 5 (quasi-random presentation of the visual cues and correct arm). No difference in performance

was seen between the sign heifers and no-sign heifers in Experiment 3, possibly due to a lack of salience of the stimuli used. In the current experiment, all cows were presented with visual cues, so it is difficult to directly compare their performance to the sign and no-sign heifers in Experiment 3. However, comparing the data from Table 9 (Experiment 3) and Table 15 (the current experiment) shows that cows in the current experiment made fewer errors than the sign heifers when the correct path in the double T-maze was LR and RL, and so were better at learning to solve the maze. These data suggest, then, that visual cues were not being used to solve the maze in Experiment 3. A further difference between Experiment 3 and the current experiment is that cows in the current experiment were trained to use signs in a reversal learning task prior to the double T-maze. Therefore, the reversal learning task may have helped to establish better stimulus control in the current experiment as compared to Experiment 3 in which reversal learning was not trained.

The current data also show that cows can learn to solve more complex mazes. A decrease in the number of errors made is one measure of maze learning and has been reported with other large animals, e.g., horses (Kratzer et al., 1977; McCall et al., 1981). Each cow was presented with eight maze problems; of which 19 of 22 mazes with signs were solved, but only 3 out of 10 mazes without signs were solved. In general, fewer errors were made in mazes with signs present (see Table 16) and as the correct path was learned, fewer errors were made within a session. While the time taken (i.e., running time) to solve a maze problem is one measure of maze learning, examination of the running times within each session of the current experiment showed that time taken for cows to complete a trial did not decrease. All trials tended to be completed within a similar duration, therefore, running time was not analysed here.

Kilgour (1981) conducted a comprehensive investigation of maze learning in cattle in which he presented both visual and non-visual problems, but did not provide internal visual cues. His maze was fully enclosed, so external maze cues could also largely not be seen from within the maze. The maze problems presented in the current experiment were comprised of open passageways, in which the pipe fencing was not covered to create walls in an effort to maintain a realistic setting that approximated that which cows may experience on-farm. So in one sense the path was always visible,

although it was difficult for people, and presumably also difficult for cows, to differentiate the correct path from the rest of the pipe fencing. Additional feed bowls were also placed at the ends of open but incorrect paths to prevent cows simply approaching a single feed bowl. Despite these differences, the current results support the maze learning Kilgour reported, in that, cows learned to solve complex maze problems.

Kilgour (1981) reported that difficulty was shown when the correct path of a maze problem involved a deviation from a direct diagonal pathway, suggesting that cows may have difficulty solving detour problems. Maze problems in the current experiment involved between five and 11 turns, with travel required in opposite directions of at least two or more portions of the maze. Whether these mazes contained a strict detour problem is partly a question of semantics. The simplest form of a detour problem usually consists of a U-shaped barrier and requires initial movement directly away from the goal followed by a sequence of movements towards the goal (Candland, 1968). Variations of this design have been used previously (e.g., Davis, 1957; Heaton, 1978; Pongrácz et al., 2005; Regolin et al., 1995; Schiller, 1949; Wolff & Hausberger, 1996). It is clear some of the maze problems presented in the current experiment had at least some common features to detours in that they required some movement away from the goal before moving towards the goal (e.g., Mazes D1 and D2). Cows 3112 and 3978 did not complete Maze D1 with and without signs, but this may have been due to the disruption in behaviour seen as a result of the alternation of sign presentation and removal for those cows, which will be discussed later. All cows except 3112 learned to solve Maze D2 with signs, suggesting that the detour-like feature in this maze was learned. The other maze problems, while not true detours, generally contained a starting point which was at right angles to the end goal and involved at least one direction change in the correct path and were also generally solved by cows when signs were present.

It is not realistic to compare the current findings with those of Arave et al. (1992) since so few trials were conducted in their study. However, the results from number of trials completed in the current experiment suggest that Arave et al.'s calves may have shown improved performance had they been presented with more trials.

The current data suggest that cows were using the visual cues to solve the complex mazes presented. Cows generally achieved the criterion on maze problems when

there were signs, but did not when there were no signs (with the exception of two cases), suggesting that mazes without signs were more difficult to solve than mazes with signs. As mentioned above, the current experiment presented mazes in a realistic environment and provided additional internal maze cues that could be used to select the correct path to solve the maze. External maze cues were still available, but the data suggest that the provision of additional visual cues in the form of yellow signs was controlling behaviour rather than other cues that may have been available. If maze learning was occurring through place learning, an increase in the number of errors made would be expected as the maze problems changed. An increase in the number of errors was not seen consistently when cows were presented with a new maze. Cows 3112, 3978 and 7841 all completed a correct first trial on Maze A (signs), and on nine occasions all cows selected the correct path in a new maze after making one error and so had selected the correct path on the second trial (see Table 16). These data suggest the use of the internal visual cues provided.

Further evidence that strong stimulus control was established in the complex maze problems was shown when the behaviour of two cows (3112 and 3978) was disrupted by sign presentation and removal. For these cows, presentation of visual cues was alternated across the first four mazes completed (i.e., signs present/signs removed/signs present/signs removed). After correctly solving Maze A with signs, both cows stopped responding when signs were removed in Maze B (see Figure 30). When signs were reinstated in the following maze (Maze C), responding was initially slow but the maze was correctly solved. A repeat of this pattern was seen with the next maze (Maze D1), in which signs were again removed. Both 3112 and 3978 failed to complete this maze, and also failed to solve the following maze (Maze E) even though signs were reinstated. Furthermore, 3112 failed to complete her seventh maze, despite signs being present.

The disruption of behaviour seen suggests that these cows had learned what to do in the presence of a yellow cue (i.e., approach it) and had also learned not to enter paths containing no yellow cue. When no visual cue was present at a path, cows continued with the behaviour of not entering. This suggests that both compound stimuli (sign and no-sign) had come to control different behaviours, i.e., the cows had learned something about S+

(sign) and had also learned something about S- (no-sign). These data support the findings of Experiment 1, which suggested that cows learn discriminations through stimulus-approach. However, these particular cows had had considerable previous experience with visual cues prior to exposure to complex mazes, which could have contributed to this finding.

The rapid cessation of behaviour shown by 3112 and 3978 when presented with a maze with no signs may also be understood if complex maze learning is regarded as a chain of responses. Catania (1992, p.123) defines a response chain as “a succession of different operants, each defined by the reinforcing consequences of producing an opportunity to engage in the next until the sequence is terminated by a reinforcer.” Completion of each portion of a chain (link) is accompanied by a stimulus change. Similarly, mazes require the completion of one response (turn) before the next response and so on leading to the end goal. Evidence suggests that behaviour can be disrupted when a simple schedule is converted to a chain schedule by the addition of new dependencies and stimulus changes. Catania provides an example in which a pigeon first learns to peck a white key before the introduction of a chain which requires the separation of key pecks into four sequences of 50 pecks, with each sequence associated with a different coloured key (blue, green, red, yellow). The introduction of such a chain has an effect on key pecking behaviour. Catania reported a decrease in responding, particularly in the early links of the chain and suggests that this is typical of behaviour on chain schedules.

That behaviour is more easily disrupted and under weaker control at earlier rather than later points in a chain has also been shown by Marsh (1982) and Thomas (1964) who reported lower response rates in initial chain sequences by domestic hens and pigeons respectively. Davison (1976) uses the analogy of public transportation to demonstrate how choice of travel shows the same effect. He points out that the decision to drive or bus to work may be made on the basis of the number of links in the chain attributed to each mode of transport rather than overall duration. For example, there are fewer links involved with driving (drive then walk to destination) and a greater number of links involved with taking the bus (walk to bus stop, then ride the bus, then walk to destination). Taking the bus may actually result in other factors increasing the links of the

chain (e.g., waiting time, changing of buses etc.). As the number of responses in the chain increase, it is expected that a person will opt for driving over bussing because performance is harder to maintain in the early sequences of a chain when more links are involved (Davison, 1976).

Catania (1992) states that a reduction in responding in the early links of a chain can be explained by considering the relationship between a response and time to reinforcement. For example, for the pigeon pecking the white key, key pecking at the start of the sequence is not different from key pecking at the end of the sequence, but after the introduction of a chain, key pecking when the key is blue (i.e., early on the chain) never produces reinforcement, so is very different from key pecking when the key is yellow, which indicates the last link in the chain and access to reinforcement. In the current experiment, when visual cues were re-instated, cows were faced with stimuli effectively at the beginning of the required chain of behaviour. Hence, re-establishment of correct maze performance might be expected to be slow when animals are faced with the requirement of starting at the beginning of the maze.

It is also possible that a tandem schedule, rather than a chain schedule, was operating in the current experiment. Tandem schedules also require a sequence or link to be completed before the next sequence is presented, however, rather than chain schedules, tandem schedules present each sequence in the presence of a single stimulus (Catania, 1992). If presentation of the yellow stimuli at each sequence or choice point in the maze is regarded as the same stimulus, then maze learning here may be likened to learning on a tandem schedule. If presentation of the yellow stimuli at each choice point is regarded as a change in stimulus, whereby the change between yellow at choice point 1 is very different to yellow at choice point 2, then this may be regarded as a chain schedule. Regarding the mazes as a tandem schedule does not offer any clear explanation as to why the behaviour was disrupted for 3112 and 3978, while regarding the mazes as a chain schedule offers an explanation that is not unsupported by the data.

Previous research with cattle suggests a rapid cessation of responding when there is a delay between completing a response and access to reinforcement. Wredle et al. (2006) showed this when training cows to respond to an acoustic signal to approach an AMS. They had essentially established a chain in which cows had to respond to the

acoustic signal, and then make their way to the AMS. However, responding rapidly ceased when responses were not immediately reinforced due to delays arising if the AMS was occupied or cows of low social rank had to wait behind higher ranked animals. These factors could also be regarded as extra links in the chain to gain reinforcement. How cows behave under chain or tandem schedules is not known and so further investigation in this area is needed.

In the current experiment, efforts were taken to avoid disrupting the behaviour of the last two cows to progress to Condition 6. Therefore, the alternation of sign presentation and removal did not occur for 7841 and 3420, rather, these cows completed all five mazes with signs before signs were removed for the last three mazes. As a result of this procedural change, the same behaviour disruption as described above was not seen. However, these cows were able to correctly solve Maze A (both 3420 and 7841) and Maze F (7841 only) without signs. Correct responding in Maze A without signs may be attributed to the fact that both cows had already learned the correct path to solve Maze A when it was presented with signs three sessions earlier. Therefore it is possible that their previous experience contributed to their performance. An increase in performance and memory retention to solve mazes has also been reported in horses (Marinier & Alexander, 1994). Cow 7841 also solved Maze F without signs, which was the eighth and final maze presented. Before experiencing Maze F, 7841 had extensive experience walking around the yard area to locate an end goal containing food. In addition, this cow was not experimentally naïve, and had prior experimental experience of the yard area from Experiment 1. Therefore these factors may have improved her ability to solve this maze even without signs present. It should be noted that even considering the prior experience with Maze A and the extensive practise before solving Maze F, that more trials were required, and that generally more errors were made to solve these mazes.

When learning an AMS, cows must learn to select the correct path to reach the dairy. Regular pasture rotation means that a new path must be learned almost daily. The current experiment shows that cows can learn to use a visual cue to select the correct path needed to solve complex maze problems. Cows had difficulty in learning to solve mazes when visual cues were removed, suggesting that they had learned to select paths when they were signalled by a yellow sign. These data expand on the findings of Experiment 1

and 2 that also showed cows can learn to select the appropriate path when a yellow sign is present. The current results contrast those of Experiment 3, which suggested that visual cues were not being used to solve a double T-maze. A comparison of double T-maze performance in the current experiment with that of Experiment 3 suggests that cows were using the signs to learn the maze in this case.

The current experiment showed that cows can learn to select the correct path in complex mazes when it is signalled by a yellow sign. Experiment 5 aimed to examine whether or not cows can learn to select a signalled path in one setting and transfer that learning to a new setting.

Experiment 5

The aim of the current experiment was to examine whether or not cows could be trained to select a path signalled by a visual cue in a controlled setting, and then transfer that learning to a less structured setting.

It was shown in Experiments 2 and 4 that a single T-maze is a relatively simple way of training cows to select a path signalled by a yellow sign. Therefore, cows in the current experiment were initially trained to select the correct arm of a T-maze in the same yard setting as used in previous experiments. The aim of this experiment was to then test whether or not cows could transfer learning to select the path signalled by the yellow sign to a new setting. To examine this, cows were tested for transfer of learning in a new location (a farm race). As with the previous experiments, another aim of the research was to present experimental conditions close to those which cows actually experience on farms. Therefore, the test maze contained four pathways, or arms, and was constructed at the junction of four farm races. Cows were required to select the correct arm when it was signalled by a yellow sign. Based on the results of Experiments 1, 2 and 4, it was expected that cows would learn to select the correct arm of the T-maze in the yard setting. The question was whether, based on the training to select yellow, cows would transfer this learning and select the correct arm of the test maze in the new setting.

Method

Subjects

Subjects were four experimentally naive Friesian-cross dairy cows. The cows were approximately 12 years old at the start of the experiment. All housing and maintenance were the same as for previous experiments.

Apparatus

Training sessions were conducted using the single T-maze used in Experiments 2 and 4 (T-maze 1). Signs were present in all conditions. Stimuli were the same as used for Experiments 3 and 4, and feed bowls, rubber matting, stopwatch and data book were the same as used in all previous experiments.

The intersection of a nearby farm raceway was used to form a four arm test maze (arms are numbered 1-4 on Figure 32) that was used to test for transfer of learning. Arms 1 and 2 were not used by the surrounding farm, and so had a predominantly grass base due to the lack of farm traffic. Despite these two races being grazed prior to commencement of the experiment, large amounts of grass, albeit short, still remained, most notably in arm 2 (see Figures 33 and 34 for a view of the races used). Arms 3 and 4 were connected to the larger race system of the surrounding farm, and so had a compacted sand and dirt base with a small grass verge on either side of the race.

All arms were the same approximate width (5 m) with the exception of arm 2 which was about 4 m wide. Arm length was measured from the end of each arm to the edge of the central area. This length varied; the length of arm 1 was 31 m due to a pre-existing end in the form of a fence, and the length of arm 2 was 23 m with an existing gate at its end. Arms 3 and 4 were part of the farm race system, and so needed the creation of an end in each case. Therefore an end point was approximated for these arms and an end created by placing electrified fence tape across the width of the arm (see Figure 34). This gave arm 3 a length of 16 m and arm 4 a length of 10 m. The central area connecting the arms of the maze was approximately 12 m by 10 m, measured diagonally from arm 2 to 4 and arm 1-3 respectively. In order to present the yellow sign, four gates (1.4 m wide by 1.1 m high) were removed from the yard area and secured against

a fence post in each arm. Each gate was positioned about 10 m from the central area of the maze in arms 1-3, and 6 m from the central area in arm 4.

Stimuli used were the same as used in Experiments 3 and 4, with the exception that only a single yellow sign was presented per trial. All other equipment were the same as for previous experiments.

Procedure

Session time and duration, separating of cows into pairs and the amount of food delivered as reinforcement were the same as for previous experiments. The experiment consisted of three conditions; a training condition where cows were trained to respond to the yellow sign in a single T-maze (Conditions 1 and 2), and a transfer condition (Condition 3).

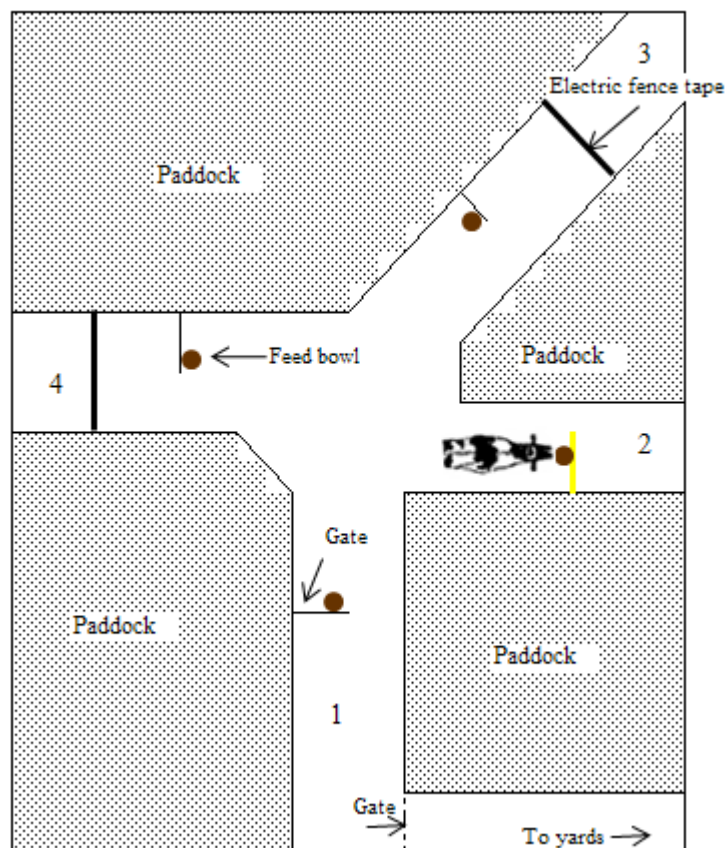


Figure 32. Diagram showing the layout of the test maze (arms are labeled 1-4).

Training. Cows were habituated to the yard area in the same manner as for previous experiments. No stimuli were present during training.

Condition 1. The procedure was identical to that used in Condition 1 of Experiment 4, in which cows were initially trained to select one arm of the single T-maze before reversing responding in the following session to the other arm once a criterion was reached. The learning criterion was five consecutive days at 88 % or above, but this was later relaxed to three consecutive days above 80 %, as two cows (1533 and 8630) failed to maintain the initial criterion.

Condition 2. Condition 2's procedure was identical to that used in Condition 3 of Experiment 4, in which the presentation of the yellow sign and the correct arm was quasi-randomly presented to each arm, with no more than three consecutive presentations in the same arm. The initial criterion was three consecutive days above 88 %, but only 1680 and 7912 achieved this before progressing to the transfer condition. Therefore, the criterion was relaxed to three consecutive days above 80 % for the remaining cows (1533 and 8630). Table 17 shows the number of sessions and trials completed by each cow.



Figure 33. Arm 1 (left plate) and Arm 2 (right plate).



Figure 34. Arm 3 (left plate) and Arm 4 (right plate), and the electrified fence tape spanning the race behind the gate and feed bowl.

Table 17.

The number of sessions and trials completed by each cow in Conditions 1 and 2.

Cow	Condition 1		Condition 2	
	Sessions	Trials	Sessions	Trials
7912	13	325	7	175
1680	12	300	7	175
8630	27	675	24	600
1533	21	525	9	225

Condition 3. Condition 3 used the test maze to assess transfer of learning to select the yellow sign. Nine trials were conducted per session for five sessions, with no learning criterion in place for these sessions. Presentation of the yellow sign was randomly determined, with an equal number of trials completed to each direction (i.e., three right, three left and three straight). Stimulus location was dependent on the arm previously visited, so whichever arm was chosen on a trial then became the start arm for the next trial. For example, if arm 2 was chosen and the next

trial required stimulus location to the right of that arm, then the correct arm for the following trial became arm 3, because this arm was positioned to the right of arm 2. One exception to this procedure was that every session started in arm 1, as this was the entry point to the test maze from the yard area. Using this procedure also meant that trials did not start in an arm unless it had been visited in the preceding trial, therefore cows never started from an arm that was never visited. Food was always present in the food bowl signalled by the yellow sign, and food was never available in feed bowls in the incorrect arm.

At the start of each session, a cow was drafted from the yard area and walked down to arm 1. Timing of a trial began when the front feet and shoulder had passed the end of the start arm, and stopped when all four feet had entered the arm selected. The experimenter walked behind the cow for every trial, but remained at a distance that did not influence arm selection. Selections of the correct arm (marked with the yellow stimulus) gave access to food and selections of the incorrect (unmarked arm) did not give access to food. On correct trials, once they reached the food, cows were given time to eat and were then moved into a small holding area between the gate and the end of the arm. On incorrect trials, cows were moved into the small holding area and held there while the next trial was set up. Electrified fence tape (not electrified for the duration of the experiment) was tied from the gate to the race fence to create this area (see Figure 34). Cows waited in the holding area while stimulus position and the reinforcer were being arranged for the next trial. The experimenter walked into all arms in between trials so that cows could not simply observe the location of the stimulus for the next trial. Cows were then released and walked towards the centre of the maze where the following trial began. Table 18 illustrates the total number of trials and the number of correct trials to each arm of the test maze.

Table 18.

The total number of trials and the number of correct trials to each arm of the test maze.

Cow	Arm number	Number of trials	Correct trials
1680	1	8	4
	2	6	3
	3	14	7
	4	16	6
7912	1	9	5
	2	7	4
	3	16	7
	4	13	3
1533	1	4	4
	2	10	7
	3	14	1
	4	17	0
8630	1	6	6
	2	8	7
	3	17	2
	4	14	0

Results

Performance during training was analysed by calculating the percentage of all responses that were correct across sessions, as shown in Figure 35. The dashed vertical line indicates condition changes, and the dashed horizontal line shows the criterion of 80 %. Correct responding varied for all cows during Condition 1, with the exception of 1680 who initially responded above 80 %. Both 1680 and 7912 performed at or above the initial criterion of 88 %, while the remaining cows reached 88 % in 19 sessions (8630) and nine sessions (1533) but did not maintain performance over five consecutive sessions. However, these cows responded at or above the adjusted criterion of 80 %.

Accuracy initially decreased for all cows when the yellow stimulus was presented quasi-randomly (Condition 2). The change in condition saw accuracy for 1680 decrease for two sessions. Correct responding for 8630 and 1533 was more variable, and in particular 8630 did not reach the reduced criterion of 80 % in 17 sessions. These two cows (8630 and 1533) completed more training sessions than the other cows.

Trial duration on left and right trials, and correct and incorrect trials were averaged and are presented in Figure 36. Cow 1533 took longer on average to complete a trial than all the other cows across both left and right trials and correct and incorrect trials during training. For the remaining cows, there was very little difference in trial duration on either left or right trials or correct and incorrect trials over Conditions 1 and 2. A general increase in trial duration was seen over Condition 2 for all cows.

Data from Condition 1 were also analysed by calculating the number of initial errors made for every successive reversal that occurred (i.e., all reversals were counted), as shown in the left panel of Figure 37. The dashed vertical lines indicate changes in condition. All cows were selecting the correct arm within five trials after a reversal, with the exception of 8630, who took longer to select the correct arm in one session. Data were also analysed by calculating the total number of errors made across successive reversals (right panel of Figure 37). A reduction in errors can be seen for all cows over successive reversals. A faster reduction in errors can be seen for 7912 and 1680, while 8630 and 1533 were slower to reduce errors and showed the highest number of errors across both training conditions.

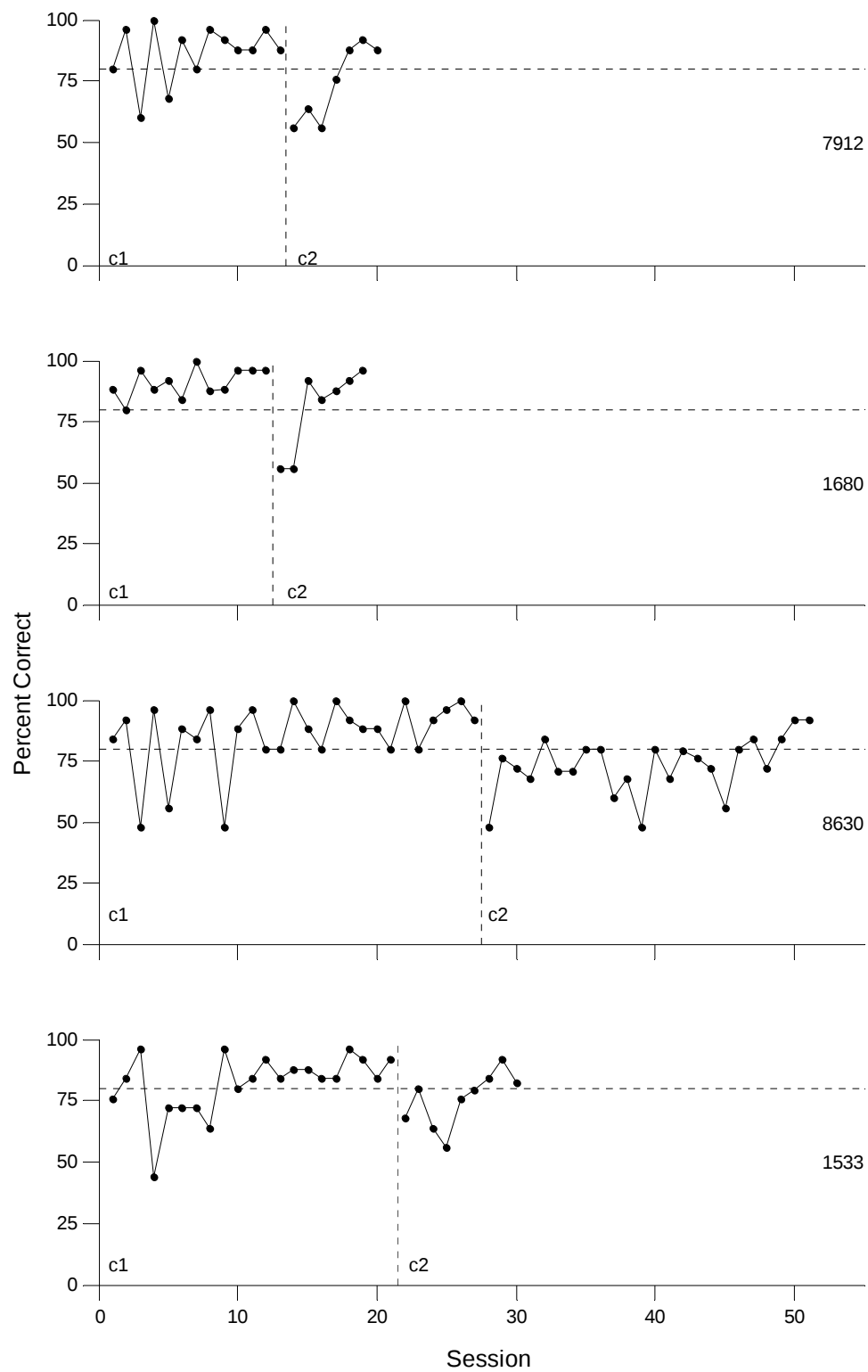


Figure 35. Percent correct for each cow in Conditions 1 and 2.

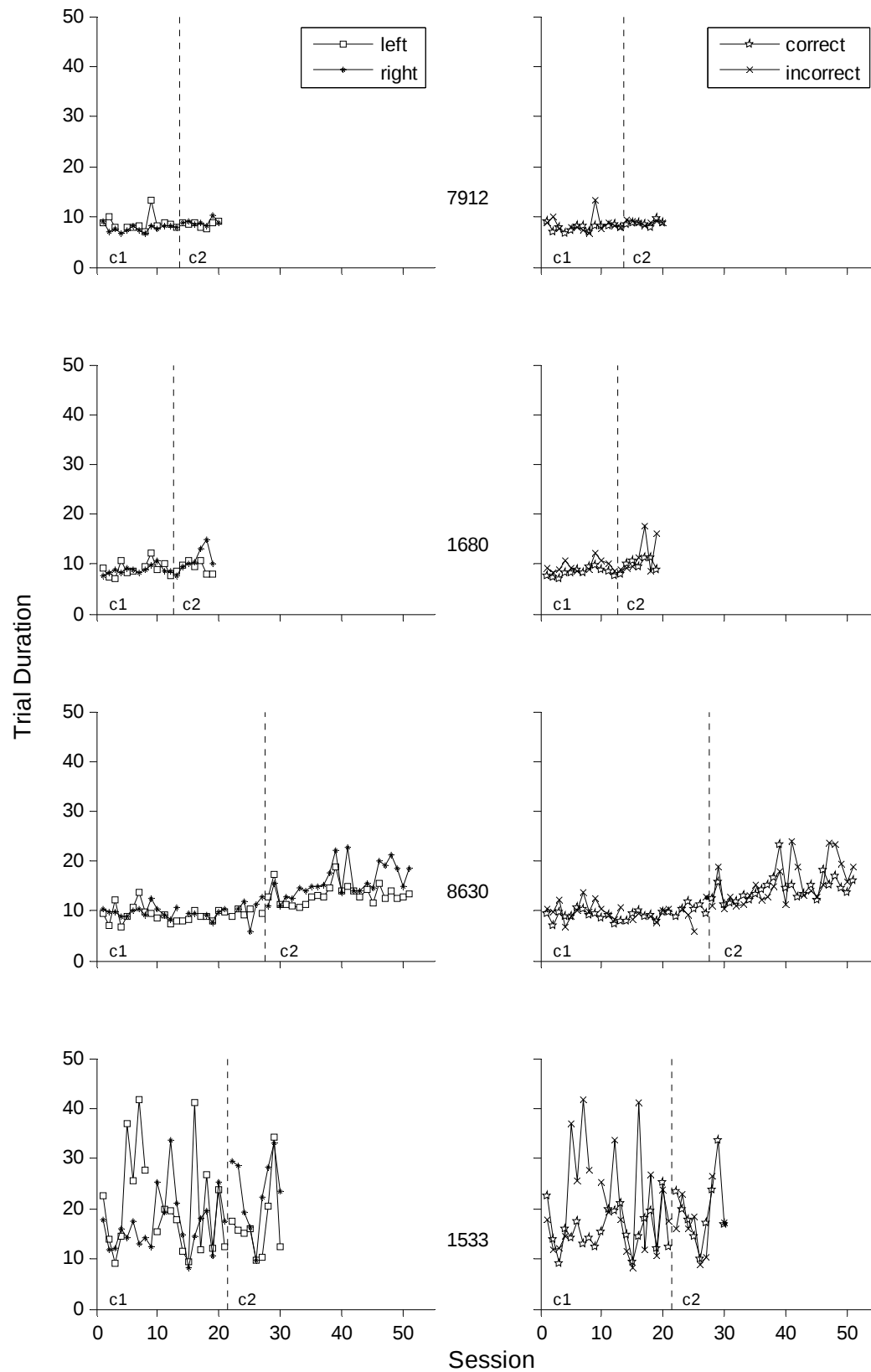


Figure 36. Average trial duration over a session for left correct and right correct trials (left panel) and correct and incorrect trials (right panel) for each cow in Conditions 1 and 2.

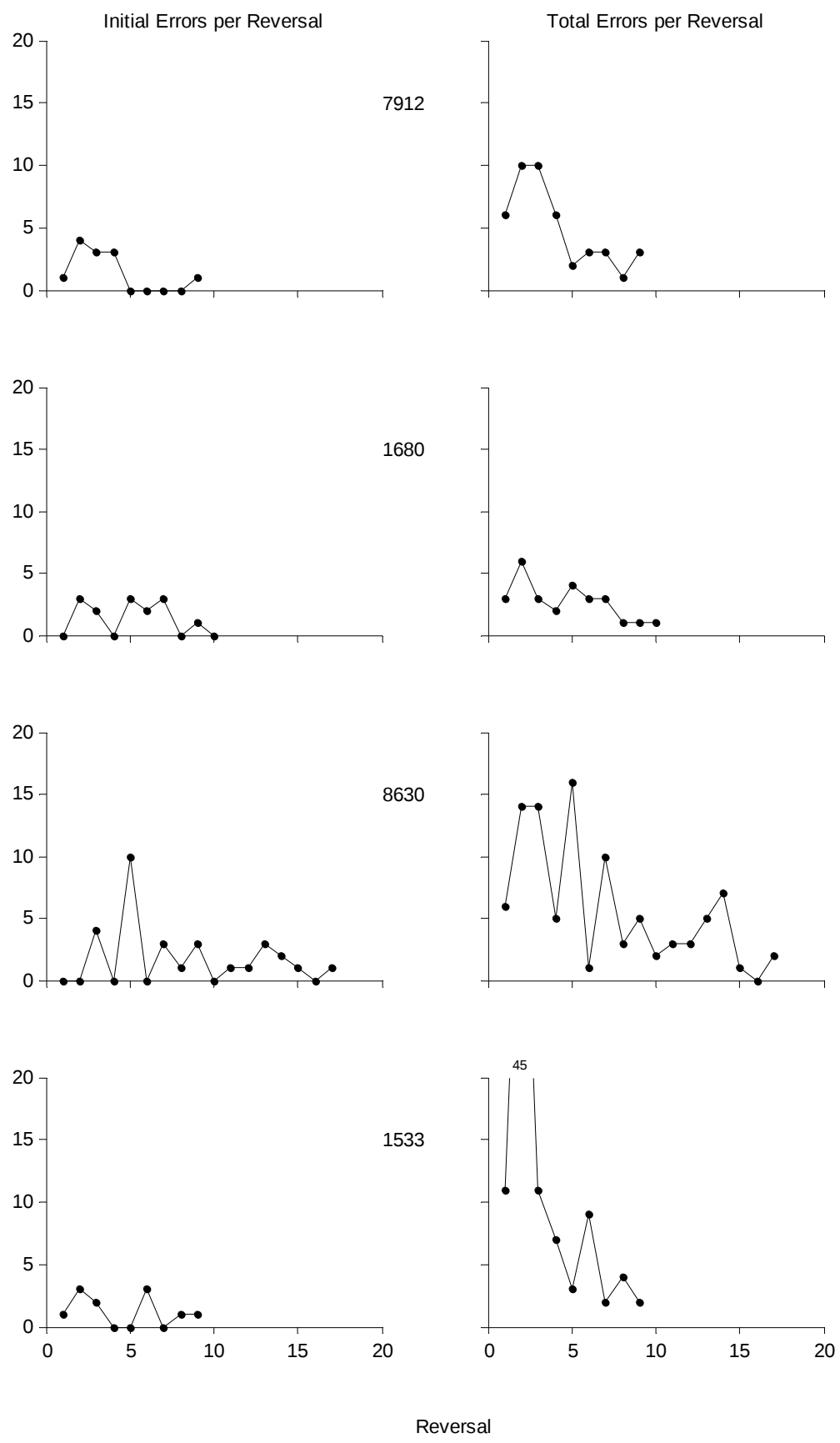


Figure 37. Initial errors made per reversal (left panel), and the total number of errors made per reversal (right panel) by each cow in Condition 1.

Data from the test maze are presented in Figures 38-41. The test maze plan is shown at the far left, and the columns represent each cow's data. Each row shows the number of starts from the start arm (indicated at S), and the number of times the correct arm (indicated by E) and the other two arms were chosen from that start arm. For example, Figure 38 shows all starts from arm 1 and all visits to the other arms when the correct arm was arm 4 (top row), arm 3 (middle row) and arm 2 (bottom row). Figure 38 shows that when arm 4 was the correct arm, all cows tended to visit arm 2. Both 8630 and 1533 never visited arm 4. Cow 1533 also never visited arm 3 when it was the correct arm, although 7912 and 1680 correctly selected arm 3 six times. In contrast, when arm 2 was the correct arm, it tended to be correctly visited by all cows, and was also visited more than the other arms, even when it was not the correct arm.

Figure 39 shows starts from arm 2 and all visits to the other arms when the correct arm was arm 1 (top row), arm 4 (middle row) and arm 3 (bottom row). All cows generally visited arm 1 when it was the correct arm, but only 7912 and 1680 correctly chose the correct arm when it was arm 4. Both 8630 and 1533 never visited arm 4. Cow 7912 and 1680 also correctly visited arm 3, while 1533 chose arm 3 once and 8630 never chose arm 3. A general pattern can be seen that when starting from arm 2, cows tended to visit arm 1, irrespective of whether this was the correct arm.

Starts from arm 3 and visits to the correct arm when it was arm 2 (top row), arm 1 (middle row) and arm 4 (bottom row) are shown in Figure 40. When trials started in arm 3 and the correct arm was arm 2, cows always incorrectly visited arm 1. When the correct arm was arm 1, three of the four cows correctly visited this arm once. No figure was generated for 1533, as she never visited arm 3 and so never started any trials from that position. When the correct arm was arm 4, cows still tended to visit arm 1, and only one cow (1680) correctly chose arm 4 on one occasion. Overall when starting from arm 3, arm 1 was visited more than the other arms.

Starts from arm 4 and visits to the correct arm when it was arm 3 (top row), arm 2 (middle row) and arm 1 (bottom row) are shown in Figure 41. With arm 3 as the correct arm, only 1680 correctly visited the arm twice, while the other cows never visited this arm when starting from 4. Arms 1 and 2 were chosen more than arm 3. Both 7912 and 8630 never started in arm 4 when the correct arm was arm 2, 1680 correctly visited arm 2 once, and 1533 continued to choose arm 1. Both 8630 and 1533 never started in arm 4 when the correct arm

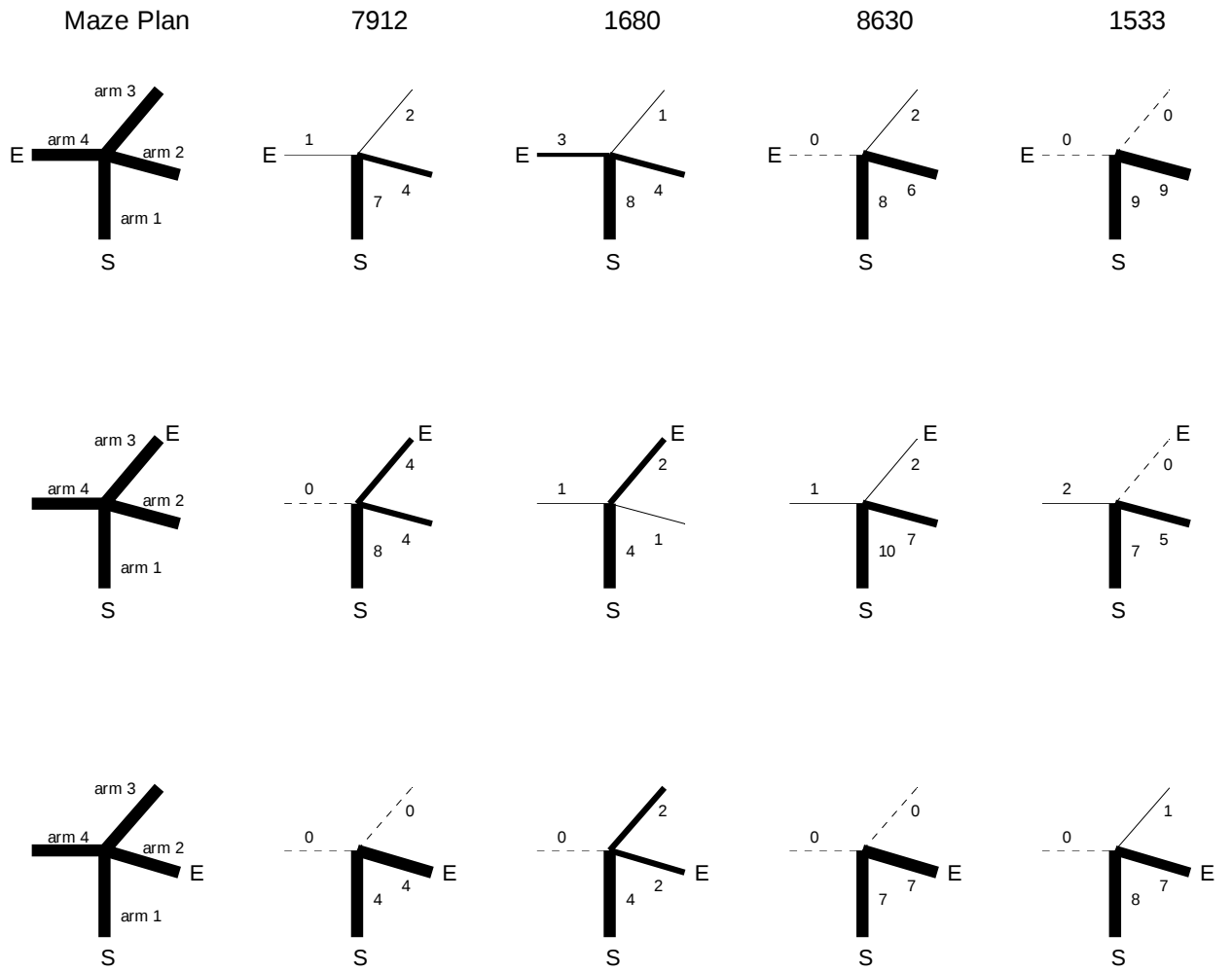


Figure 38. Starts from arm 1 when the correct arm was arm 4 (top row), arm 3 (middle row) and arm 2 (bottom row).

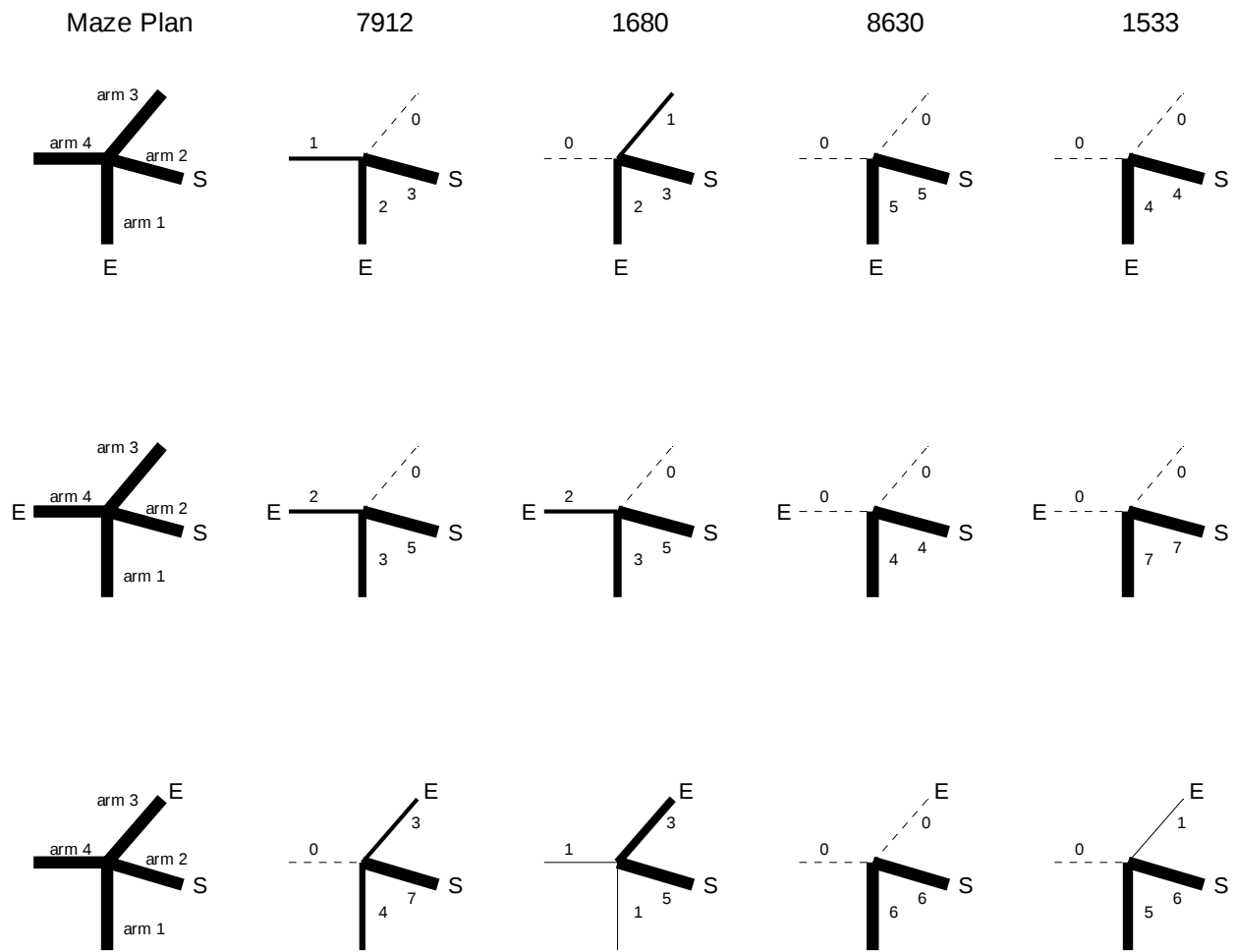


Figure 39. Starts from arm 2 when the correct arm was arm 1 (top row), arm 4 (middle row) and arm 3 (bottom row).

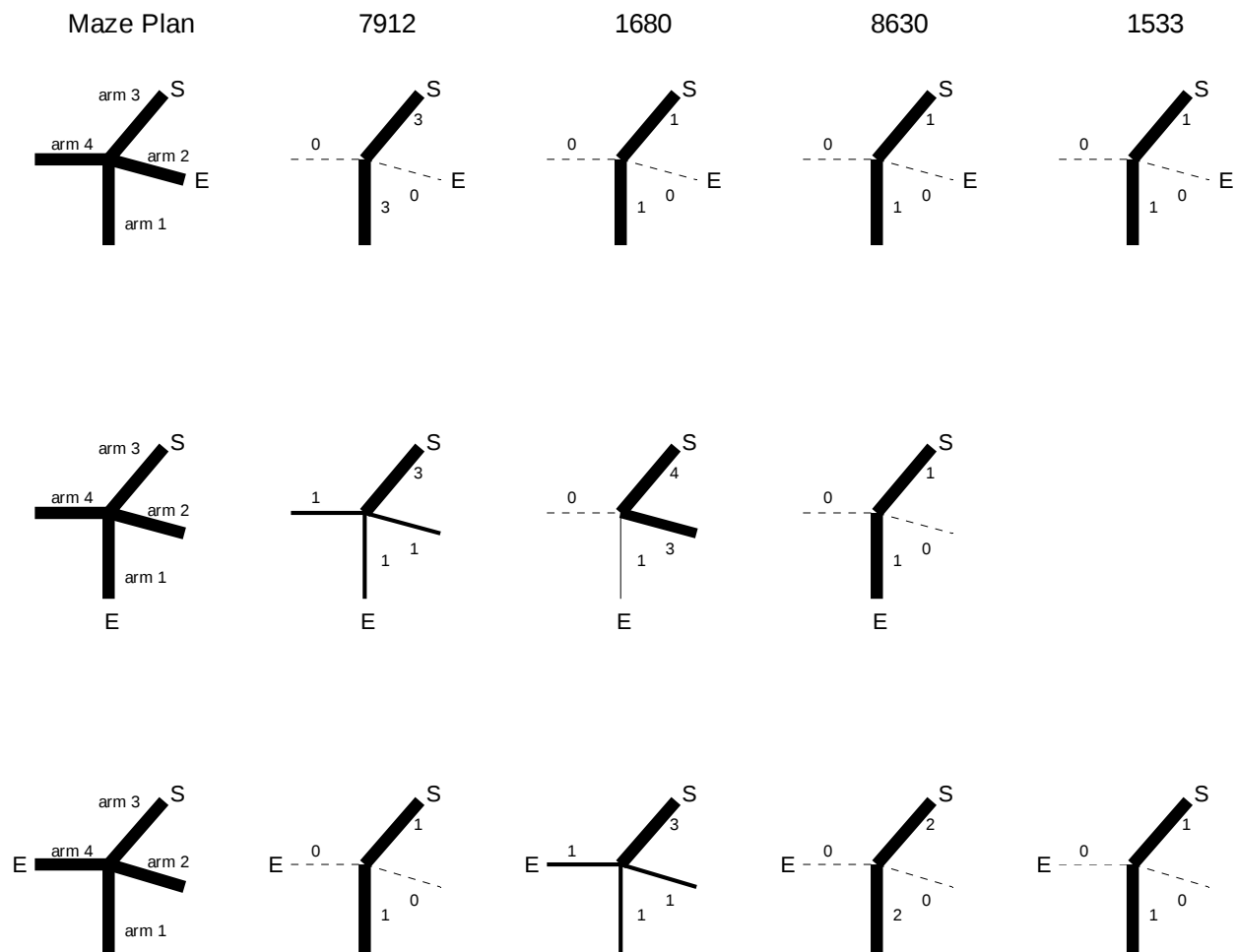


Figure 40. Starts from arm 3 when the correct arm was arm 2 (top row), arm 1 (middle row) and arm 4 (bottom row).

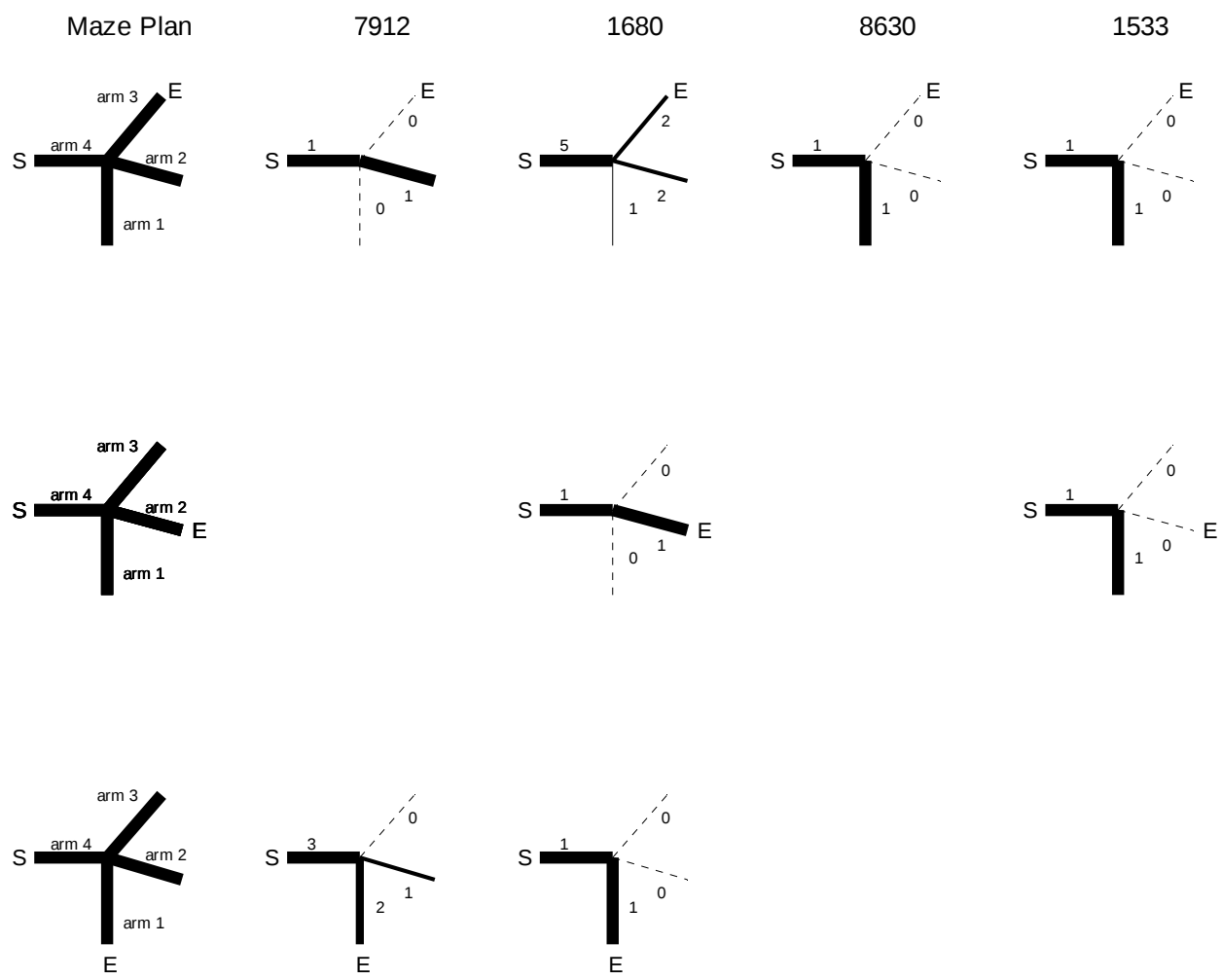


Figure 41. Starts from arm 4 when the correct arm was arm 3 (top row), arm 2 (middle row) and arm 1 (bottom row).

Table 19.

The number and percentage of selections to the correct and incorrect arms of the test maze.

1680					7912				
Session number	Correct arm selected	Incorrect arm selected	% correct arm	% incorrect arm	Session number	Correct arm selected	Incorrect arm selected	% correct arm	% incorrect arm
1	1	7	12.5	87.5	1	4	5	44.4	55.6
2	5	4	55.6	44.4	2	4	5	44.4	55.6
3	5	4	55.6	44.4	3	3	6	33.3	66.7
4	5	4	55.6	44.4	4	5	4	55.6	44.4
5	4	5	44.4	55.6	5	3	6	33.3	66.7
1533					8630				
Session number	Correct arm selected	Incorrect arm selected	% correct arm	% incorrect arm	Session number	Correct arm selected	Incorrect arm selected	% correct arm	% incorrect arm
1	2	7	22.2	77.8	1	3	6	33.3	66.7
2	3	6	33.3	66.7	2	3	6	33.3	66.7
3	2	7	22.2	77.8	3	1	8	12.5	88.9
4	1	8	11.1	88.9	4	6	3	33.3	33.3
5	4	5	44.4	55.6	5	2	7	28.6	77.8

Table 20.

The number of times the correct and incorrect arms were selected, and whether the arm contained grass. Also shown is the total percentage of selections to arms that contained no grass and the total percentage of selections to arms that contained grass.

1680							7912						
Session number	Correct arm no grass	Incorrect arm no grass	Correct arm grass	Incorrect arm no grass	Total % no grass	Total % grass	Session number	Correct arm no grass	Incorrect arm no grass	Correct arm grass	Incorrect arm no grass	Total % no grass	Total % grass
1	1	3	0	4	50.0	50.0	1	2	1	2	4	33.3	66.7
2	2	0	3	4	22.2	77.8	2	1	0	3	5	11.1	88.9
3	2	0	3	4	22.2	77.8	3	1	1	2	5	22.2	77.8
4	5	1	0	3	66.7	33.3	4	3	1	2	3	44.4	55.6
5	3	2	1	3	55.6	44.4	5	3	1	0	5	44.4	55.6
1533							8630						
Session number	Correct arm no grass	Incorrect arm no grass	Correct arm grass	Incorrect arm no grass	Total % no grass	Total % grass	Session number	Correct arm no grass	Incorrect arm no grass	Correct arm grass	Incorrect arm no grass	Total % no grass	Total % grass
1	1	1	1	6	22.2	77.8	1	1	2	2	4	33.3	66.7
2	0	0	3	6	0.0	100.0	2	0	1	3	5	11.1	88.9
3	0	0	2	7	0.0	100.0	3	0	0	1	8	0.0	100.0
4	0	2	1	6	22.2	77.8	4	1	0	5	3	11.1	88.9
5	0	0	2	7	0.0	100.0	5	0	0	2	7	0.0	100.0

was arm 1, but 7912 and 1680 correctly visited the correct arm twice and once respectively. Generally when there was a start from arm 4, cows always visited arm 1 or arm 2.

Table 19 shows the number of times the correct and incorrect arms were selected in the test maze. Percent correct for 1680 increased after her initial session to 55.6 %, which is above chance in a three-choice task (33 %). Accuracy was above chance for 7912 in three out of five sessions, but accuracy was at chance levels for session 3 and 5. Percent correct for 1533 was at or below chance for all sessions with the exception of the last session, where 44.4 % of selections were correct. Accuracy for 8630 was also at or below chance except for session 4, where she achieved 66.7 % correct. Table 19 shows that 1533 and 8630 selected an incorrect arm more than a correct arm.

Table 20 shows the number of selections to the correct and incorrect arms and whether they contained grass. Also shown is the total percentage of selections to the grassed and non-grassed arms. Cow 1680 selected non-grassed arms above chance in sessions 1, 4 and 5. For her remaining sessions, she selected arms that contained grass. Cow 7912 also selected arms that contained grass more than arms that did not contain grass. Both 1533 and 8630 clearly selected arms that contained grass more than arms that did not contain grass.

Chi-square Goodness-of-fit tests were used to analyse if there was a significant difference in the number of visits to the correct arm and the other arms for any cow. The results of these tests were not significant for any cow (7912, $\chi^2(1)=1.600$, $p>.05$; 1680 $\chi^2(1)=2.529$, $p>.05$; 8630 $\chi^2(1)=0.000$, $p>.05$; 1533 $\chi^2(1)=0.900$, $p>.05$). A further analysis was then carried out to determine whether the presence of grass in two of the arms was a confounding variable, i.e., whether the presence of grass was independent of or dependent on whether the arm did or did not contain the yellow sign. Chi-square tests of Independence showed that the variables were dependent for two cows (7912 $\chi^2(1)=6.79$, $p<.05$ and 1680 $\chi^2(1)=5.97$, $p<.05$) and independent for two cows (8630 $\chi^2(1)=0$, $p>.05$ and 1533 $\chi^2(1)=0$, $p>.05$).

Discussion

The cows in this study learned to select the correct arm in a single T-maze when that arm was signalled by a yellow sign, supporting the results of previous experiments. However, cows did not select the correct arm when it was signalled by a yellow sign in a test maze, so did not transfer learning from the training setting to the test maze setting.

The reversal learning task was not learned as well by cows in the current experiment compared to cows in Experiments 2 and 4. This was shown by the lower percentage of selections to the correct arm by two cows (8630 and 1533), although the other two cows (1680 and 7912) did achieve a criterion of 88 % correct, which was the same criterion used in Experiments 2 and 4. Despite this performance, a decrease in errors over successive reversals was seen, indicating that cows had learned the reversal task. It was not clear why 1533 and 8630 were not as accurate as the other cows at this task. A comparable number of trials were completed in the previous experiments; in Experiment 2, sign cows completed 763 trials, and in Experiment 4 cows completed between 435 and 556 trials. Cows in the current experiment completed between 475 and 1275 trials, with 8630 and 1533 actually completing the most trials (1275 and 750 respectively). Therefore, the poor performance seen cannot be attributed to a lack of exposure to training, but may be as a result of these cows not learning the task as well as previous cows. Wide individual differences in learning have been reported elsewhere in horses (i.e., Fiske & Potter, 1979; McCall, et al. 1981; Wolff & Hausberger, 1996) and cows (Rushen et al., 1998).

The current experiment failed to achieve good transfer of learning across settings. If immediate transfer had occurred, a high percentage of correct selections to the target arm would have been expected in the first session in the test maze. Accuracy for 7912 was above chance in her first session with 44.4 % correct, but accuracy for the remaining cows in their first session was either at or below chance. Transfer may have also been shown by cows learning to select the correct arm, as all correct trials gave access to food. Accuracy increased only for 1680, while accuracy for the remaining cows varied. These results suggest that transfer did not occur in this case. These data support previous findings that cows did not transfer behaviour learned in one location to another location (e.g., de Passille et al., 1996; Wredle et al., 2004; Wredle et al., 2006). Wredle et al. (2006) trained cows to respond to an auditory signal while indoors but saw poor responding to the same signal when tested outdoors. They suggested that the failure to respond to the signal at pasture may have occurred because no training was given in that location. Renken et al. (2008) trained heifers

to approach a visual cue that was paired with food in a test location, and then compared their performance with untrained heifers in a pasture location. They reported that generalisation did occur, but perhaps crucially, they trained heifers over two days at the pasture location before testing to determine if learning had been transferred from the original training location. Cows in the current experiment were trained in the new setting, as food was available if the correct arm of the test maze was selected, however, the number of correct selections did not increase (i.e., the cows did not learn) as a result of food availability. Therefore, a failure to show transfer of learning may have been due to other factors.

Stokes and Baer (1977) point out that generalisation may not occur if enough stimuli that were present in the original training setting are not also present in the new setting. In Renken et al.'s (2008) study, an orange cone and two feed tubs (one containing food) were present in the test setting. An orange cone and a feed tub (it is not clear if there were two) were also present at the pasture setting, where an alleyway was constructed for training prior to testing at pasture. It is possible that the alleyway was similar to the original training setting, and the presence of the other stimuli helped to promote generalisation, although this was not discussed. In the current experiment, the only elements programmed to be common in both the training and test maze setting were the yellow sign and the feed bowls and trays used for food delivery. Half-gates that were also in the yard setting were used for stimulus presentation, but the surrounding environment i.e., open pasture and fencing, was very different from the yard context in which cows had seen the gates previously. As such, the failure to show transfer of learning may have been due to the lack of common stimuli in the new setting, and it may be that a greater number of common elements need to be present in order to achieve some transfer. How many common stimuli need to be in a new setting in order for cows to transfer learning is not known, and is an area in need of further research.

It is also possible that the results were affected by the presence of grass in the test maze setting, which may have reduced the effectiveness of the food provided as reinforcement. Despite the area being grazed prior to the commencement of trials, large amounts of short grass were still present in arms 1 and 2 (see Figure 33). Cows tended to visit the arms with grass present irrespective of whether the sign was or was not present (see Table 20). An increase in the percentage of selections to arms that contained grass shows that cows had learned to select those arms. It was confirmed that the presence of the sign had no effect on the selections of two cows (8630 and 1533), suggesting that selection was not being controlled by the sign in the new context of the test maze setting. Wredle et al. (2006) suggested that their failure to achieve transfer of learning to respond to an auditory signal in a

pasture setting may have been due to the level of grass at pasture. Cows at pasture can be reluctant to leave that setting, and in particular, pasture levels have been identified as a factor that reduces cow movement to milking (Davis et al., 2006; Ketelaar-de Lauwere et al., 2000). Experiments 2 and 4 showed that transfer occurred within a yard setting, so an alternative area was needed to test for transfer in the current experiment. Limited sites offered an area that was large enough and close enough to where the cows were housed; therefore the presence of some grass was unavoidable. Confounding variables, such as grass, need to be better controlled, particularly in research where animals experience some food deprivation.

The current experiment showed that learning to select a path when it was signalled by a yellow sign on a gate did not transfer to this new task and setting. This may have been as a result of the new setting being too different from the training setting and not containing enough common stimuli to promote transfer.

General discussion

This series of experiments investigated various aspects of cows learning to navigate mazes with and without signs. Experiment 1 showed that cows could learn to attend to a visual cue in an experimental setting similar to the types of yards they may encounter on an AMS farm. Cows were successfully trained to approach a pair of gates with a yellow sign (S+) when it was presented opposite a pair of gates with a grey sign (S-) in a simultaneous discrimination. Test sessions showed that cows were using the stimuli, as they tended to approach S+ and also avoid S-. These findings showed that there is potential for visual cues to be used as a ‘sign’ or signal to help cows select a path. Experiment 1 also examined whether or not learning to select a path on the basis of a yellow sign could be transferred to a new setting. Good transfer of learning to select the yellow sign was not seen, but transfer may have been affected by a lack of common stimuli in the new setting.

Table 21.

Summary of the main features and findings of each experiment.

	Summary of experiment	Summary of results
Experiment 1	Task: Select the gate marked with a yellow sign to get access to food in a simultaneous yellow vs grey discrimination	Cows learned to approach S+ and avoided S-. Learning did not transfer to a new location.
Experiment 2	Task: Select the correct arm of a T-maze to get access to food in a reversal learning task. Some cows were provided with a yellow sign to indicate the correct path and some were not.	Cows learned to reverse responding and approached the arm of the T-maze signalled by the yellow sign. No-sign cows, at best made one error before learning that a reversal had taken place, sign cows could reverse responding immediately. Learning transferred to new mazes presented within the same location.
Experiment 3	Task: Select the correct path in a double T-maze to get access to food. Some heifers were provided with yellow signs indicating the correct direction to turn and some were not.	Sign and no-sign heifers achieved a similar and high level of accuracy in learning the double T-maze. Thus the sign heifers did not appear to have learned to approach the yellow signs.
Experiment 4	Task: Select the correct path in a T-maze (using a reversal learning task) to get access to food when the correct path was signalled by a yellow sign. Then cows had to select the correct path in a double T-maze and in more complex mazes when the correct path was sometimes signalled by yellow signs and sometimes not.	Cows learned to approach the yellow signs in both the single (reversal learning) and double T-mazes. Cows were better at selecting the correct path in complex mazes with the signs present than when there were no signs – suggesting they were approaching the paths with the signs in these more complex mazes. Thus, learning transferred to new mazes presented within the same location.
Experiment 5	Task: Select the correct path in a T-maze to get access to food (using a reversal learning task), then assessed whether learning transferred to an on-farm setting.	Cows learned to approach the yellow sign in the T-maze, but did not transfer this learning to the test maze in a farm setting.

Experiment 2 expanded on these results and showed that cows could learn to select the arm of a T-maze (i.e., reverse responses) in which a visual cue was presented and could use this cue to ‘solve’ a reversal learning problem. Cows did transfer learning to select the yellow sign in new T-mazes that were within the same yard setting as the original T-maze used for training. In Experiment 3, the stimuli were changed so that they resembled those that might be realistically used in a farm setting. Experiment 3 showed that heifers were able to solve a double T-maze with two choice points and four choices of direction, but no difference in accuracy was seen between the sign and no-sign heifers, suggesting that the visual cues provided were not being used to solve the maze. Thus, it was speculated that the initial reversal learning task in Experiment 2 may have influenced these results, in that, reversal learning made the yellow sign relevant. Experiment 4 used reversal learning, together with the same stimuli used in Experiment 3, and showed that cows could learn to use visual cues to select the correct path in more complex mazes. Therefore, the results of Experiment 4 suggest that adequate stimulus control was not established in Experiment 3. Experiment 4 also showed that cows could learn to use signs in novel mazes within the same setting (i.e., the yard). Experiment 5 showed that learning to use signs did not transfer to a totally new setting, and that the inclusion of more stimuli (the yellow sign, the feed bowls and gates from the yard) at that new setting did not promote transfer of learning. The main features and results of each experiment are outlined in Table 21.

The results of Experiment 1 add to the findings of previous research (e.g., Baldwin, 1981; Entsu et al., 1992; Rehkamper & Gorlach, 1997; Rybarczyk et al., 2003; Schaeffer & Sikes, 1971; Taylor & Davis, 1998; Wieckert et al., 1966) reporting discrimination learning in cattle. In addition, data from Experiment 1 support the suggestion that, rather than using response-selection, cows may learn discriminations by stimulus-approach, as the positive stimulus was approached and the negative stimulus was avoided in test trials. While previous research has not specifically addressed the learning process in place, stimulus-approach has been suggested by several studies (e.g., Baldwin, 1981; Blackmore et al., (unpublished); de Passille et al., 1996; Munksgaard et al., 1997; Taylor & Davis, 1998) and has been implied in studies reporting avoidance of stimuli (e.g., Arnold et al., 2008; Lee et al., 2007; Munksgaard et al. 2001). Other research (e.g., Entsu et al., 1992; Rehkamper & Gorlach, 1997; Wieckert et al., 1966) has not addressed what has been learned in the discriminations reported. Further research may clarify the learning process cows use to acquire discriminations.

To the author's knowledge, only one study (Lensink et al., 2006) has examined reversal learning in cows. Other studies (i.e., Grandin et al., 1994; Hosoi et al., 1995a), while not true investigations of reversal learning, have suggested that cows will not reverse a previously learned response. Experiment 2 clearly showed that cows could learn to select the arm of a T-maze in which a visual cue was presented and reverse responding to the other arm. Furthermore, Experiment 2 showed that the no-sign cows could solve a reversal learning problem as well as other animals (e.g., monkeys (Harlow, 1949)) and that the sign cows could use the visual cue provided to reverse responses immediately. The results of Experiment 2 also suggest that reversal learning was an effective method to train cows to use a visual cue. Reversal learning was included in Experiments 4 and 5 as a method to train cows to learn to use the yellow sign to select the correct path in a maze. The data show that cows did use signs to solve maze problems in these experiments. However, Experiment 3 did not initially train cows using a reversal task, and cows did not learn to use signs to solve a double T-maze in that experiment. These results suggest that merely placing the yellow signs in a maze was not adequate enough to establish stimulus control, and that the reversal task in Experiments 2, 4 and 5 made the visual cue more relevant. Therefore, reversal learning may be an appropriate method of teaching animals to attend to visual stimuli.

The results of the current series of experiments support the limited research that has demonstrated maze learning in cattle (e.g., Arave et al., 1992; Arave et al., 1992; Kilgour, 1981). None of the above studies examined whether or not cows could learn to use an additional internal maze cue to solve a maze. Experiment 4 showed that cows could use signs to learn complex maze problems. Cows solved each daily maze problem when signs were present, but had more difficulty solving mazes when signs were removed. Experiment 3 showed that heifers learned a double T-maze, although the data suggested that signs were not being used to learn the maze in that case. Heifers in Experiment 3 had learned the double T-maze by either response or place learning, although which of these processes was occurring was not able to be determined. To the author's knowledge, no published research has investigated whether cows are response or place learners, but given the farming context in New Zealand, an investigation seems relevant and would contribute to the existing literature. The current experiments show, that regardless of whether cows learn mazes by learning responses or places, signs can facilitate learning of the maze, particularly if cows have been initially trained to use signs.

Limited research has investigated whether or not cows can learn to transfer behaviour learned in one setting to another setting. de Passille et al. (1996), Wredle et al. (2004) and Wredle et al. (2006) reported that cattle did not transfer behaviour trained in one setting to another setting, however, Munksgaard et al. (1997), Rushen et al. (1998) and Renken et al. (2008) did report that behaviour transferred across locations. Experiments 1 and 5 failed to show transfer of learning to select a yellow sign in a new setting. In both experiments, the new setting was very different to the training setting. In Experiment 1, the new setting was a stand-off paddock, and in Experiment 5, the new setting was at the junction of four farm races. In contrast, the training setting in both of these experiments was a yard, in which the environment was fairly uniform (i.e., it was a concrete yard with nothing else in it except for pipe fencing). As such, the stand-off paddock and the farm races had little in common with the yard area (i.e., there was no pipe fencing and mainly trees, grass and dirt). Stokes and Baer (1977) point out that generalisation may not occur if stimuli common to both settings are not present. These results suggest that cows need to have sufficient stimuli occurring in common to both the training setting and any new setting for good transfer of learning to occur. How many stimuli are sufficient to promote transfer is not clear. In addition to a lack of common stimuli, in Experiments 1 and 5 the general setting may have been too different to promote good transfer. Further research could identify factors that affect transfer in cows and examine methods to promote transfer across multiple locations.

One limitation with cow research is it is often restricted to few numbers (Soffie et al., 1980). It was not possible to purchase cows for this series of experiments, but cows were able to be borrowed from a nearby AMS farm. Cows available for experimental use were either empty (i.e., not in calf and not being milked) or more typically, dry (i.e., they were in calf but not being milked). However, because the animals came from a commercial farm, each experiment was somewhat constrained by calving dates, by which time cows had to be returned to the farm for calving. Therefore, experiments could not exceed 6 months. Experiment 3 was of shorter duration than the other experiments because of further constraints (i.e., heifers had to be returned for mating). In addition, the available pasture levels could only accommodate four cows at a time. Running each experimental condition was also labour intensive. Given these factors, cows were not the easiest subject for study.

The current series of experiments show that there is potential for cows to learn to use a sign in order to select the correct path to reach a milking shed. Using visual cues may reduce the amount of time needed to train cows to find the correct path, which is an area of

difficulty with regards to training on AMS farms in New Zealand. These findings have the potential to be applied to the area of observational learning, in which animals learn through the presence of other animals (Nicol, 1995). Wechsler and Lea (2007) suggest that merging trained individuals with naïve individuals is more beneficial than training a group of naïve animals. Training in this manner may also reduce the costs associated with the training of individuals (Nicol, 2006). Observational learning has not been extensively investigated in cows, but the benefits of social learning have already been utilised on a prototypical AMS farm in New Zealand. There, it was observed that naïve cows learned from cows already experienced in the AMS, thus speeding up the learning process. Given such preliminary findings, there may be potential for naïve cows to learn to use a sign by interacting with individuals already trained to use visual cues on an AMS farm.

In conclusion, the current findings show that the use of signs can facilitate maze learning in dairy cows. Specifically, these experiments have shown that cows can learn to use signs to select the correct path in various mazes. The findings reported here have the potential to assist cows in learning how to locate the correct path to reach the dairy as it changes on a daily basis. When training cows to learn an AMS farm, sufficient stimuli common to a training setting should be included in settings where there is an expectation that learning will be transferred. These findings may be applied to AMS technology when it is combined with fully pasture based farming.

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