Exploring expert opinion on the practicality and effectiveness of biosecurity measures on UK dairy farms using choice modelling

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ABSTRACT

Biosecurity – defined as a series of measures aiming to stop disease-causing agents entering or leaving an area where farm animals are present – is seen as very important to the continuing economic viability of the UK dairy sector and for animal welfare. This study gathered expert opinion from farmers, veterinarians, consultants, academics, government and industry representatives on the practicality and effectiveness of different biosecurity measures on dairy farms. The study used best worst case scenario modelling, a technique which is seen to allow greater discrimination between choices and avoid variability in interpretation associated with other methods such as Likert scales and ranking methods. The results showed that keeping a closed herd was rated as the most effective measure overall, and maintaining regular contact with the veterinarian as the most practical measure. Measures relating to knowledge, planning and veterinary involvement; buying in practices; and quarantine and treatment scored highly overall for effectiveness. Measures relating to visitors, equipment, pest control and hygiene scored much lower for effectiveness. Overall, measures relating to direct animal to animal contact scored much higher for effectiveness than measures relating to indirect disease transmission. Some of the most effective measures were also rated as the least practical, such as keeping a closed herd and avoiding nose to nose contact between contiguous animals, suggesting that real barriers exist to farmers implementing the biosecurity measures that are needed on dairy farms. There was heterogeneity in expert opinion on biosecurity measures e.g. veterinarians rated effectiveness of consulting the veterinarian on biosecurity as significantly more effective than dairy farmers, suggesting a greater need for veterinarians to promote their services on farm. Though, both groups rated it as a practical measure, suggesting that this relationship still holds some advantages for the promotion of biosecurity.

Keywords: Biosecurity, disease control, effectiveness, practicality, best worst scaling.

INTRODUCTION

Biosecurity – defined as a series of measures aiming to stop disease-causing agents entering or leaving an area where farm animals are present (Defra, 2003) – is seen as very important to the continuing economic viability of the UK dairy sector and for animal welfare (Defra et al., 2004). The 2004 Animal Health and Welfare Strategy for Great Britain emphasises the responsibility of animal owners in managing animal health risks and states that costs should be increasingly born by the industry rather than tax payers, putting increasing onus on farmers to tackle problems (Defra et al., 2004). The strategy also states that veterinarians (hereafter referred to as 'vets') are uniquely placed to promote animal health and welfare and should be at the forefront of delivering proactive disease prevention services. In a European context a 2013 proposal for a regulation on animal health, which will be implemented after 2016, similarly states that animal owners and professionals are in the best position to manage animal health and that vets should play an active role in disease prevention and raising awareness of disease risks (European Commission, 2013).

There is little consensus however over which biosecurity measures are deemed to be the most effective for stopping the spread of disease (Valeeva et al., 2011). A number of reviews have been carried out synthesising information about the effectiveness of biosecurity measures or the risk of disease introduction through different pathways, (which can be seen as the corollary of evaluating the effectiveness of a biosecurity measure) from field trials and other types of evidence (Wells, 2000; Cooke & Brownlow, 2008; Maunsell & Donovan, 2008; Mee et al., 2012). A number of studies have focused on particular diseases or conditions (Horst et al., 1996; Sørensen et al., 2002; Valeeva et al., 2005; Garabed et al., 2009; Gorden and Plummer, 2010; Gates et al., 2013; Kuster, 2013). However, there is still lack of evidence for effectiveness for many biosecurity measures that are recommended on the dairy farms, and some maintain that quantifying the effectiveness of a biosecurity measure based on experiments in controlled conditions is not the ideal approach to biosecurity because of the difficulty in extrapolating these findings to working farms (Kuster, et al., 2015). Studies of farmers' attitudes to biosecurity have reported that the effectiveness of different measures is very important to them; farmers do not want to take time to carry out practices that do not bring substantial benefits (Garforth et al., 2013). The practicality of measures has also been shown to be important to farmers; if the measure is effective but impractical to implement then they are unlikely to carry it out (Kristensen & Jakobsen, 2011; Valeeva et al., 2011). However, there are no studies that have explicitly looked into the practicality of biosecurity measures on dairy farms.

The dairy sector in the UK is the third largest milk producer in the EU and the tenth largest in the world (Bate, 2016). Trends in the dairy sector in the UK have been in line with those of other industrialised countries with a decreasing number of farms, increasing herd size and milk yield (AHDB Dairy, 2016). The average herd size in the UK in 2015 was 142 cows, and the average milk yield was 7944 litres per cow per year (AHDB Dairy, 2016). The majority of dairy farms in UK operate a mixed grazing and housing system, with cows grazing in summer months and housed during the winter months (The Andersons Centre, 2013). A smaller number operate a low input year round grazing system, or a high input year round housing system. Since the 2001 foot and mouth disease (FMD) outbreak the government has been ceding control over certain areas of biosecurity to industry, as outlined in the 2004 Animal Health and Welfare Strategy for Great Britain (Defra, 2004). An exception is Scotland where the Scottish Government introduced a mandatory scheme to eradicate bovine viral diarrhoea (BVD) (Voas, 2012).

The elicitation of expert judgement is often used in situations where problems are complex, there is a lack of data and there is a need for action (Slottje et al., 2008; Martin et al., 2012). Bijker et al. (2009) state that in situations of "complex risks", the most appropriate course of action can be to try to clarify the factual base for making decisions on risk management and improve the reliability and validity of scientific knowledge by consulting with experts. A small number of expert studies have also been carried out looking into the most important or effective biosecurity measures. Van Winden et al. (2005) undertook a systematic review of risk factors for the introduction of four common cattle diseases and held an expert opinion workshop asking experts to attribute a percentage risk to each risk factor and a risk reduction factor to different biosecurity measures. Sayers et al. (2014) asked expert vets and veterinary practitioners to rate the importance of a number of biosecurity measures on dairy farms using a Likert scale measuring importance.

There are a number of limitations associated with these studies. First these studies only focussed on asking experts to rank effectiveness or importance of a measure without considering their relative practicality, secondly, these studies used Likert scale or rating scales to gather expert opinion which have methodological deficiencies. For example, Likert scales and rating scales can involve a "scale equivalence" which means that people may interpret a ratings scale differently, and this may vary significantly across cultures (Adamsen et al., 2013). There may be acquiescence bias in that people tend to respond positively to questions more frequently than they respond negatively (Whitty et al., 2014). Rating and Likert scales also may not discriminate sufficiently between items, which may be given the same or similar ratings (Louviere et al., 2013). Methods which ask people to rank items can become too cognitively demanding and unfeasible for more than seven items (Louviere et al., 2013).

A technique which overcomes these methodological deficiencies is best worst case scaling (BWS) (Finn and Louviere, 1992). BWS is a choice method which presents people with a set of options, usually four or five, and asks them to pick the best and the worst (Louviere et al., 2013). The method is often used to obtain information about preferences across a large number of items, as it is not as cognitively demanding as ranking many items (Adamsen et al., 2013). It also avoids scale bias where respondents only use part of a scale or where they interpret the scale in different ways (Cohen and Orme, 2004). BWS has been used in a range of different disciplines and contexts, to elicit consumer preferences in market research (Adamsen et al., 2013), health (Lancsar and Savage, 2004) and in an agricultural context it's been used to gather expert opinion on different greenhouse gas emissions mitigation measures on sheep farms (Jones et al., 2013) and to assess the effectiveness and practicality of measures to control *E. coli* O157 on cattle farms (Cross et al. ,2012).

The aim of this study is to use best worse scaling choice modelling to gather expert opinion from vets, farmers, academics, consultants, industry and government representatives on the relative practicality and effectiveness of different biosecurity measures on dairy farms in the UK. The aim is to bring greater clarity to debates in the dairy sector about what biosecurity measures farmers can and should carry out in conjunction with their vet and contribute to debates about initiatives that could improve biosecurity in the dairy industry.

MATERIALS AND METHODS

Study Design

Recruitment of Experts.

In this study expert opinion was gathered from expert vets, farmers, academics, consultants, industry and government representatives. Expertise means substantive knowledge on a particular topic that not everyone has, and an expert is someone who holds this knowledge (Martin et al., 2012). There may be different types of expertise and experts: that which is acquired through formal training and research, and that which is based on experience (Martin et al., 2012) and on professional standing and performance (Burgman et al., 2006). Pearson et al. (2007) state that expertise in a health care context involves both knowledge and experience, as practitioners balance external information and their own experience when making clinical decisions. This can also be seen to be true in the case of farm animal health. Thus the aim of the sampling process for this study was not to access a representative sample of the vet, farmer and other populations, but to use purposive sampling that aimed to access relevant expertise within these groups.

In this study expert vets were defined as those who held a relevant postgraduate qualification: either a Royal College of Veterinary Surgeons (RCVS) certificate or a diploma in cattle health and production (CCHP and DCHP) or status as a fellow or honorary fellow of the RCVS, as Slottje et al. (2008) maintain that professional awards and other signs of peer recognition can be taken to denote expertise. In addition it was stipulated that the vet must carry out all or most of their work in farm animal practice and have a minimum of 8 years clinical experience. An expert farmer was defined as a farmer who considers biosecurity and disease control on farm to be a key priority and rate their biosecurity on their farm as high. Expert farmers could operate different types of dairy system e.g. open or closed herds, zero grazing or spring/summer grazing, conventional or organic. Farmers were included as experts because it was considered that specially screened and selected farmers would have the requisite experiential and knowledge-based expertise on biosecurity to take part in the study. Expert farmers gain experience on their farm and inform themselves on biosecurity through a wide range of sources (Brennan and Christley, 2013). The inclusion of farmers as experts can be seen as analogous to the growing understanding of patients as experts on disorders which they experience (Paterson and Thorne, 2000). Expert patients are considered to have experiential and knowledge-based expertise which can inform other patients, and they have day to day experiential expertise on the disorder, which clinicians do not (Hartzler and Pratt, 2011). Farmers have also been included as experts whose local expertise can inform policy and practice, in areas such as water quality protection (Oliver et al., 2012). Other experts included people from industry, academia, government and consultancy who had substantial knowledge and experience about biosecurity and would be able to answer the questions in relation to effectiveness and practicality of biosecurity measures on farms.

Expert vets were selected through lists of RCVS veterinary practitioners (RCVS, 2016) and telephone calls with veterinary practices were made to verify selection criteria. Expert farmers, those fitting the criteria, were contacted through project links with the industry levy body the Agriculture and Horticulture Development Board (AHDB) Dairy, through AHDB field extension officers and through a brief questionnaire to farmers which included questions asking them to rate the effectiveness of their biosecurity practices on their farm (scale 1-5) given to farmers at two prominent livestock and dairy events in England in 2015. A list of other academic, industry, consultant and government biosecurity experts was generated through literature searches and prior knowledge of expertise thorough published work. All the selected experts were contacted by email with information and a link to the survey in May 2015. A reminder email was sent if the person did not fill out the survey.

Survey Design.

In order to develop the list of biosecurity measures used in the survey, an initial list of 72 measures was compiled from existing published biosecurity guidelines and advice to farmers. This list was then narrowed down to 30 measures which were deemed to be the most important, based on reviews of the literature. A group of three expert vets at the School of Veterinary Medicine and Science, University of Nottingham were then consulted on the comprehensiveness and the wording of this list. The survey was piloted with a group of 8 expert vets. The list of 30 measures used in the study can be seen in Table 1.

For the purposes of the study, biosecurity was defined as both bioexclusion: preventing the introduction of disease causing agents onto the farm, and biocontainment: stopping the spread of disease causing agents to other parts of the farm and off the farm. The 'effectiveness' of a measure was defined as how well it prevents disease-causing agents entering or leaving any place where farm animals are present. The 'practicality' of a measure was defined as the ease with which the measure could be implemented by the farmer. This can involve issues of physical, financial and cultural feasibility, among other considerations.

The survey was designed and uploaded as a web survey using Sawtooth Software SSI Web 8.3.13. Optimal survey designs were selected based on the following criteria: frequency balance so that each item (biosecurity measure) appears an equal number of times in the survey; orthogonality meaning that items are paired together an equal number of times; connectivity meaning that pairs are designed in such a way that all items are connected; and positional balance so that items are presented an equal number of times in different positions (Erdem et al., 2012). The biosecurity BWS survey consisted of twenty five effectiveness questions asking the respondent to pick the most and least effective out of a set of five biosecurity measures, and twenty five practicality questions asking the respondent to pick the most and least practical out of a set of five biosecurity measures. An example of a BWS question used in this survey can be seen in Table 2.

Basic demographic information was collected. Farmers were asked how many milking cows were in their herd; their age; what region of the UK their farm was in; whether their buying practices could be classed as open, open with biosecurity practices or closed; whether they practiced year round housing, seasonal grazing and housing or year round grazing; and how effective they rate the disease control measures on their farm. Vets were asked in what year they qualified as a vet; what region of the country they practice in; what proportion of their time is spent on dairy farm work; and what percentage of that time is spent in a disease prevention advisory role. Other experts were asked about the nature of their employment and the nature of their expertise in relation to disease control on dairy farms.

Analysis

Data analysis was carried out using a multinomial logit (MNL) model in a Hierarchical Bayes framework, which are based on Random Utility Theory (RUT). RUT is the framework that underlies most discrete choice experiments and assumes that a person's relative preference for item A over item B is revealed in how often they choose item A over item B (Thurstone, 1927). It assumes that there is an underlying subjective scale behind people's choices, and the utility for each item is a measure of the item's location on that scale (Louviere et al., 2013). We can express the utility of item *i* as:

$$U_i = V_i + \varepsilon_i$$

Here the utility for item i (U_i) is made up of the explainable, systematic component V_i and the stochastic, unexplainable component ε_i.

If we assume that the unexplainable component ε_i follows a Gumbel distribution then this creates a multinomial logit (MNL) model that can be used to estimate the probability of each individual choosing any item as best. In this MNL the probability that the individual chooses the *ith* item as best (or in this study, most effective or most practical) from a set of K items can be expressed as:

$$P_i = \frac{e^{ui}}{\sum e^{uk}}$$

Where e^{ui} is the antilog of the utility for item i, and e^{uk} is the antilog of the utility scores for each item in the set of K items.

The probability of choosing the *jth* item as worst (or least effective or least practical) in a set of K items can be expressed as:

$$P_j = \frac{e^{-uj}}{\sum e^{-uk}}$$

Where e^{-uj} is the antilog of the negative utility for item *j*, and e^{-uk} is the antilog of the utility scores for each item in the set of K items.

The probability that a person will choose the pair *i* and *j* as best and worst respectively is the probability that the difference in utility between *i* and *j* is greater than the difference in utility between any other pair in the set of K items. This probability can be expressed in conditional logit form as:

P(i is chosen best and j is chosen worst)

$$= \frac{e^{\mathrm{Ui}-\mathrm{Uj}}}{\sum_{b=1}^{K}\sum_{w=1}^{K} e^{Ub-Uw} - K}$$

Where b stands for the best choice and w for the worst choice.

For more about the MNL model and HB analysis see (Mcfadden, 1980; Flynn et al., 2008; Sawtooth Software, 2009a; 2009b; 2009c; 2009d). A fit statistic was also calculated which shows the internal consistency of each respondent's answers. Sawtooth Software calculates each respondent's fit statistic as the root likelihood, based on the likelihood that they will pick each of the answers they did, given their other answers (Sawtooth Software, 2014). A minimum fit statistic is calculated as 1/c, where c is the number of items per set. In a study asking respondents to pick from set of 5 choices then a random set of scores would predict the respondent's answer correctly 20% of the time, generating a fit statistic of 0.20. A minimum fit statistic of 0.2 was stipulated in this study because there were 5 options to choose from. All respondent's fit statistics in this study exceeded the minimum suggested fit statistic, so all responses were retained. The model was run for 20,000 'burn–in' iterations followed by another 10,000 more iterations which were then saved and averaged to produce the scores for each measure.

The practicality and effectiveness scores for a single measure were compared using a t-test and Mann-Whitney U test (Petrie and Watson, 2013) was used to investigate if effectiveness was scored significantly different to practicality.

In order to explore the heterogeneity or degree of agreement and disagreement among experts for the set of measures, estimate scores distributions were computed with a mean for each respondent for each measure drawn from best worst choices (Cross et al., 2012). Then for each measure a coefficient of variation was calculated and any values above 1 were considered to indicate heterogeneity (Adamsen et al., 2013). For measures exhibiting heterogeneity, post–hoc comparisons (using ANOVA test and a Tukey HSD post-hoc test, or a nonparametric Kruskal-Wallis test and Dunn-Bonferroni post hoc test, depending on the distribution of the data) between expert groups' scores were conducted to see if significant differences existed between respondent groups. Ethical approval for the study was obtained from the School of Veterinary Medicine and Science, University of Nottingham.

RESULTS

Response Rate

In total 84 expert vets were invited, 28 completed the survey and 8 partially completed the survey, giving in a total usable response rate of 33%. A total of 36 other experts were contacted, of these 16 completed the survey and 3 partially completed the survey, giving a usable response rate of 44%. Out of 62 farmers contacted, 16 completed the survey and 3 partially completed the survey, giving a useable, response rate of 26%. Descriptive statistics of the respondents are shown in Table 4. All respondent's fit statistics in this study exceeded the minimum suggested fit statistic, so all responses were retained.

Best Worst Scaling Scores

The estimated mean effectiveness and practicality scores for each measure from choice modelling are shown in Table 4. For the purposes of analysis the different measures were grouped into sets of measures relating to knowledge, planning and vet involvement; quarantine and treatment; buying practices; grazing livestock; animals re-entering the farm; pest control; visitors, equipment and hygiene, which can be seen in Table 4. The measure rated most effective overall was measure 7, maintain a closed herd; followed by measure measures 14, prevent nose to nose contact with neighbouring animals by maintaining adequate fencing; measure 12, test new animals bought onto the farm to assess their disease status; and measure 6, implement rapid culling of persistently infected animals where it is appropriate for the disease. The most practical measure was measure 3, maintain regular contact with the vet; followed by measure 16, do not spread fields with imported slurry; measure 13, avoid hiring bulls; and measure 2, establish a herd health protocol e.g. through using a herd health plan.

Figure 1 shows a scatter plot presenting measure's effectiveness scores on the Y axis and the practicality scores on the X axis. The scores were normalised so that the average practicality and effectiveness scores were 0 and the standard deviation was 1. If the measure scored above average for practicality then it appears to the right hand side of the Y axis. If it scored above average for effectiveness then it appears above the X axis. Measures in the upper right quadrant are both above average for effectiveness and practicality, and measures in the lower left quadrant score below average for both practicality and effectiveness. In total nine measures scored above average for both practicality and effectiveness.

Measures relating to knowledge planning and veterinary involvement, measures 1, 2 and 3 all scored above average for effectiveness and practicality. Measure 3 had a significantly higher practicality score than effectiveness score (P=0.007). Measure 30, vaccinate for diseases not already on the farm, scored slightly below average for effectiveness and below average for practicality. In terms of measures relating to quarantine and treatment, measures 5 and 6, vaccinate for diseases already on the farm, and implement rapid culling of persistently infected animals, respectively, also scored above average for both practicality and effectiveness. Measure 4, isolating sick animals and monitoring their disease status scored around average for effectiveness and below average for practicality. Any measures relating to isolating or quarantining animals: measures 4, 11, 18 and 19 scored below average for practicality.

All 7 measures related to buying in livestock scored above average for effectiveness, with the exception of measure 9, consulting with the seller farmer before buying in animals. Several measures related to buying in livestock had with significantly higher ($P < 0.05$) effectiveness than practicality scores: measures 7 ($P<0.001$), 10 ($P<0.001$), 11 ($P<0.001$), 12 ($P<0.001$). Measure 8, consulting with the seller farmer's vet, and measure 10, viewing accredited test results, as well as measure 12, testing new animals brought on to the farm, scored above average for practicality. Measure 13, avoid hiring bulls, was rated as one of the most practical measures. Measure 14 relating to preventing nose to nose contact between neighbouring animals by maintaining adequate fencing had a significantly higher effectiveness than practicality score ($P<0.001$). Measure 16, do not spread fields with imported slurry had a significantly higher practicality than effectiveness score ($P<0.001$). The rest of the measures relating to isolating animals re-entering the farm, pest control, visitors, equipment and hygiene all scored below average for effectiveness, with the exception of measure 18, isolating young re-entering the farm after being housed elsewhere, which had a significantly higher effectiveness than practicality score (P<0.001). Most also scored below or near average for practicality, with the exception of measure 18, maintain good hygiene on the farm which scored above average for practicality.

Another useful way to divide the data was exploring measures relating to minimising or eliminating disease risk through *direct contact* between farm animals, what will be referred to as "direct measures", and measures which relate to *indirect contact* between animals, relating to fomites or to higher level strategic measures such as disease planning and monitoring, these will be referred to as "indirect measures". The scatter plot in Figure 2 divides the normalised data into direct and indirect measures. Direct measures scored higher than indirect measures for effectiveness, with only two direct measures scoring below average for effectiveness: measures 9 and 19, and three indirect measures scoring above average for effectiveness: measures 1,2 and 3 relating to planning and recording herd health status.

Choice Heterogeneity

Thirteen measures showed some heterogeneity in effectiveness scores with coefficient of variation above 1 (Table 5). Of these measures, 7 had significant (P<0.05) differences between respondent groups' scores. The vet respondent group for instance rated measure 3, maintain regular contact with your vet and discuss disease prevention and herd health status, as significantly more effective than the farmer respondent group (P=0.002). Farmers rated measure 20, prevent wildlife accessing housing sheds and food supplies as significantly more effective than vets (P=0.001). And vets rated measure 30, implement a programme of preventive vaccination for diseases not already on the farm, as significantly more effective than the farmer (P=0.013) and other respondent groups (P<0.001). Nineteen measures showed some evidence of some heterogeneity in practicality scores. Of these, 11 had significant differences among scores between respondent groups' scores. The vet group rated measure 5, vaccinate to control diseases already on the farm as significantly more practical than the farmer group (P=0.041). The farmer group rated measure 7, maintain a closed herd, as more practical than the vet group (P=0.014) and other groups (P=0.006). Farmers also rated measure 14, prevent nose to nose contact with neighbouring animals by maintaining adequate fencing, as more practical than the vet group (P<0.001) and the other group (P=0.015).

DISCUSSION

This is the first study exploring both effectiveness and practicality of biosecurity measures implemented on dairy farms using choice modelling and also first study that includes farmer choices in expert opinion for biosecurity.

One key finding of the study is that measures relating to direct animal to animal contact were rated as being clearly more effective than measures relating to indirect contact. These were measures related to buying in new animals; reintroducing animals to the farm; and nose to nose contact between animals on contiguous farms. This point is reiterated in the literature (Van Winden et al., 2005; Defra, 2006; Cooke & Brownlow, 2008; Sibley, 2010; Mee et al., 2012). The effectiveness of direct and indirect measures will depend on the epidemiology of the disease, as diseases which are highly infectious but fragile such as bovine herpesvirus type 1 (BVH-1) are more likely to be spread by direct contact, whereas pathogens which are more robust and can survive in the environment for longer, such as the foot and mouth disease virus and bovine tuberculosis virus, are more likely to be spread by indirect contact (Sibley, 2010). However, there was a clear trend in the data showing the higher effectiveness of direct measures.

Within direct measures, the high effectiveness scores of buying in practices is supported in the literature (Maunsell & Donovan, 2008; Gorden & Plummer, 2010) in particular, keeping a closed herd was also cited or rated reviews and experts studies as the most effective or important measure (Van Winden et al., 2005; Cooke & Brownlow, 2008; Mee et al., 2012; Sayers et al., 2014). But maintaining a closed herd scored below average for practicality. Maintaining a completely closed herd is recognised as a difficult thing for a farmer to achieve and some maintain that it likely to remain so in the future as many dairy herds in Britain aim to expand production, or need to replace animals culled because of diseases such as bTB (Sibley, 2010). It was interesting to note that farmers rated keeping a closed herd as significantly more practical than vets and others. This may be because the farmers surveyed in this study were “expert” farmers who defined themselves, or were defined by research partners, as having an interest in biosecurity, and vets and others may have been answering the questions with average farmers in mind. It could also be that farmers and vets and others were operating with a slightly different definition of what a closed herd is, as Sayers et al. (2014) found that some farmers claimed to have a closed herd but they did buy in some animals.

The second most effective measure overall, measure 14, preventing nose to nose contact between neighboroughing animals through maintaining adequate fencing, was also considered to be important in other expert studies (Van Winden et al., 2005; Sayers et al., 2014). Local disease spread, including through nose to nose contact, was considered especially important for dairy farms compared to cattle operations by Gates et al. (2013) because dairy farms tend to be relatively densely clustered in the UK. This measure also scored below average for practicality and Sibley (2010) states that adequate fencing can be expensive and difficult to maintain by individual farmers, suggesting regional approach involving cooperation between farmers may be more suitable to improve its implementation.

The results suggested that isolating animals is considered an effective biosecurity measure, but is particularly difficult for dairy farmers to achieve, as all measures relating to isolating animals (4, 11, 18, 19) scored below average for practicality. Studies have suggested that only a small proportion of farmers isolate purchased stock (Brennan & Christley, 2012; Gates et al., 2013). Farmers may not have adequate facilities for isolating animals, and that it can be very labour and time intensive to manage isolated animals separately, especially in relation to milking as this would require isolated animals to be milked separately, potentially involving disinfecting milking machines before and after use and many farmers do not have the resources to achieve this (Sibley, 2010).

Measure 10 and 12 buy animals with accredited test results and test new animals brought onto the farm to assess their disease status respectively scored highly for effectiveness, but its effectiveness can be limited by a lack of availability of accredited disease free herds to purchase from (Sibley, 2010) and poor sensitivity of some tests (Maunsell and Donovan, 2008). This seems to be reflected in the current study as for both these measures practicality scores were significantly lower than their effectiveness. Gates et al. (2013) suggested that testing and isolating bought in animals were effective measures, but action needs to be taken based on the test results, such as exclusion of these animals from the herd, or treatment. How well the biosecurity measure is carried out will also have an impact on its effectiveness, as isolation measures could be more or less rigorous and complete (Gates et al., 2013).

The only measure within the set of buying in measures which scored below average for effectiveness was measure 9 consulting the seller farmer about the animals' disease status, though vets and others rated it more practical than the farmer group. This may be because there is an asymmetry of information between seller and buyer farmer, as seller farmers may not be obliged to inform the buyer about any disease problems (Mee et al., 2012) and a large proportion of farmers can be unaware of the disease status of their animals for a particular disease at a given time (Gates et al., 2013), meaning they may not be in a position to pass this information on to the buyer.

The biosecurity measures related to buying in animals were seen as some of the most effective, yet also some of the least practical to implement. This adds a further rationale to literature that suggests that simply giving farmers more information about biosecurity will not improve biosecurity on farms (Jansen et al., 2010; Kristensen & Jakobsen, 2011). Farmers cannot implement measures that are very impractical for them. This study supports the need for a recognition of this point in the wider debate and a discussion of what individual farmers can and cannot control and where else change needs to come from (Enticott, 2008).

Measures relating to knowledge planning and veterinary involvement also scored highly for effectiveness (measures 1, 2 and 3, with the exception of measure 30). This resonates with an extensive literature on the important role of the vet as gatekeeper to and promoter of biosecurity (Cannas da Silva et al., 2006; Lowe, 2009; Orpin & Sibley, 2014; Statham & Green, 2015). Vets rated measure 3, maintain regular contact with the vet, as significantly more effective than farmers. This is perhaps unsurprising; that vets believe their services are valuable in helping to promote good biosecurity. There have been many suggestions in the literature however that vets need to become better at promoting their services as disease prevention and management consultants rather than their more traditional role of treating individual sick animals (Ruston et al., 2016). This difference between vet and farmer scores could bear this out, if even expert farmers who presumably have a good working relationship with the vet rate the effectiveness of their services lower than vets do. Interestingly, maintaining regular contact with the vet was rated as the most practical measure overall, by both farmer and vet respondent groups. This is interesting given that a number of barriers in the vet-farmer relationship have been highlighted to better implementation of biosecurity measures, including lack of farmer and vet time, farmer’s financial barriers and a perception by vets that farmers are not interested in biosecurity (Gunn et al., 2008). This could be related to the familiarity of the farmer-vet relationship meaning that vets can tailor biosecurity advice to farmers (Ruston et al., 2016).

In relation to measure 30, vaccinating for disease not already on the farm, it is perhaps surprising that this did not score more highly for effectiveness and practicality. Vets were the only group who rated this as above average for effectiveness, and rated it more highly than farmers and others. Preventive vaccination is promoted as an important measures for many common livestock diseases (Wells, 2000; Mee et al., 2012; Paton, 2013), and vaccination is a widely carried out biosecurity measure by farmers in the UK: Cresswell et al. (2014) found that 86% of farmers they surveyed had vaccinated their cattle for at least one disease in the previous year. Measure number 5, vaccinating for diseases already on the farm, scored higher for effectiveness and practicality, though vets gave it a significantly higher score for practicality than farmers. It has been shown that there is a lack of compliance with vaccination protocols in terms of timing of doses, storage, and other factors by farmers which could impact on the effectiveness of vaccinations (Cresswell et al., 2014), and veterinary advice around when and what to vaccinate for has also been shown to vary (Cresswell et al., 2013). These factors might explain the relatively low results for preventive vaccination, and why farmers see vaccination as less practical than vets see it. More work could be done however on why there was a difference in scores between vaccination as a preventive or a treatment measure, and between farmer and veterinary scores.

All indirect measures relating to pest control, visitors, equipment and hygiene were rated below average for effectiveness and most below average for practicality. Experts consulted in the studies by Sayers et al. (2014) and Van Winden et al. (2005) also rated the biosecurity risk of visitors as relatively low, and the risk from shared equipment as relatively low (Van

Winden et al., 2005). Different types of visitors will pose different levels of risk, and visitors who regularly visit other farms may pose a greater risk (Sibley, 2010).

There is arguably a need for a greater recognition in debates about biosecurity that direct measures are perceived to be more effective than indirect measures. In a study of biosecurity recommendations across different livestock species Moore et al. (2008) found that the most commonly recommended measures were indirect measures relating to equipment and visitors, with operational policies, infrastructure and animal identification being recommended less often.

BWS was best suited to evaluate a large number of measures, which are too cognitively demanding for respondents to rank in a list. The model allowed us to calculate an overall mean with credible intervals and respondent specific estimates of effectiveness and practicality, thus allowing us to investigate degree of consensus or disagreement (i.e. choice heterogeneity), which is generally lacking in evaluation of expert opinion. There was evidence of heterogeneity among experts on effectiveness and practicality of biosecurity measures, similar to the findings of Cross et al. (2012). Whilst caution should be taken when attempting to make inferences to the wider veterinary and farmer community, as we chose a purposive sample of expert farmers and vets, our results suggest that perceived effectiveness and practicality of certain biosecurity measures could differ significantly among vets and farmers and thus have implications for knowledge transfer. This variability in expert opinion could be because of lack of evidence on efficacy and practicality of these measures or different experiences among groups – further work is needed to explore sources of heterogeneity. The response rate was lowest, 26%, among the farmer expert group. Low farmer response rates to surveys is recognised as a problem among researchers, which is partly explained by "survey fatigue" as farmers get approached to fill in a large number of surveys (Pennings et al., 2002).As with all the expert opinion research which relies on nonprobability sampling, the expert elicitations in the study belong to respondents who participated in the study and may not be representative of the overall population. However, we believe by using a strict and defined expert selection criterion we have limited the potential bias. In this study the biosecurity questions were not divided by type of farm or disease separately. The effectiveness of different biosecurity measures for different diseases can depend on many factors including the transmission pathway of the disease, the time lag between exposure and acquiring the disease, whether or not the disease is zoonotic, how prevalent the disease is, how accurate tests for the disease are. And the practicality of the measure can vary according to a myriad, psychological and contextual factors on the farm (Enticott, 2008). However, it appears that there was a certain level of consistency within and between groups in the responses, such as the higher effectiveness of direct over indirect measures, and measures relating to buying in cattle. Others have also emphasised the potential for consistency across different biosecurity measures, in that one measure, such as keeping a closed herd, can be effective in relation to a number of diseases (Defra, 2006; Cooke & Brownlow, 2008; Carslake et al., 2011).

The wording of the measures is by necessity open to interpretation. Measures could also be applied in very different ways, with a potentially wide impact on effectiveness and practicality. There were also a number of measures and variations on measures that were not included in the study (Maunsell and Donovan, 2008; Mee et al., 2012).

The results also do not provide an absolute measure of how effective or practical a biosecurity measure is considered to be, but rather provide a *relative* estimation of which measures are more or less practical or effective than each other. To obtain an absolute assessment of effectiveness studies such as randomised controlled trials are necessary.

While the study was based in the UK the results can be applied to the dairy sectors in other Western countries. The UK has the second largest average herd size in the EU after Denmark and the mixed production system is typical, though some countries such as Denmark and the Netherlands could be considered to have intensive systems and countries such as Ireland to have more extensive systems (Promar International Limited, 2014). Dairy sectors in certain European countries, such as Scandinavian countries, have less endemic disease than the UK, thanks to successful eradication programs (Moennig et al., 2005). This would mean that they may make less use of vaccination as a control and prevention measure than the UK. In the US farms are on average much bigger than in the UK and systems are more intensive with cows spending more time indoors (Barkema et al., 2015). The effectiveness of measures could be seen to vary more based on the types of disease threats a country's dairy sector faces, rather than the type of production system in the country. It has been suggested that dairy farms in the US also need to improve the biosecurity of their buying practices (Barkema et al., 2015; Wells, 2000). The practicality of carrying out measures could vary more between countries based on the structure of their dairy sector and facilities on dairy farms. Where industry and government initiatives are well established to minimise the disease risk from buying in animals, such as Scandinavian countries, this could make buying in measures more practical for farmers to carry out. Minimising contact with wildlife and neighbouring animals could be more practical in systems where cows are housed for more of the year such as the US. Large farms may have more facilities for isolating cows, disinfecting equipment and more protocols for minimising disease risks from visitors, making these measures more practical. However, it is suggested that these are areas which even large farms in the US need to work on (Barkema et al., 2015).

The results of the study were disseminated and discussed in a consensus panel with vets and farmers and are made available in a report prepared for the funding body AHDB Dairy, who will also take steps to disseminate the results to farmers.

CONCLUSIONS

This study gathered expert opinion from farmers, vets, consultants, academics, government and industry representatives on the practicality and effectiveness of different biosecurity measures on dairy farms using best worst case scenario modelling. The results showed that keeping a closed herd was rated as the most effective measure overall, and maintaining regular contact with the vet as the most practical measure. Measure relating to knowledge, planning and veterinary involvement; buying in practices; and quarantine and treatment scored highly overall for effectiveness. Measures relating to visitors, equipment, pest control and hygiene scored relatively much lower for effectiveness. Overall, measures relating to direct animal to animal contact scored much higher for effectiveness than measures relating to indirect disease transmission. Some of the most effective measures were also rated as the least practical, such as keeping a closed herd and avoiding nose to nose contact between contiguous animals.

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Table 1 Biosecurity measures used in the study

Item number	Biosecurity measure
1.	Monitor and record the herd health status through regular disease testing.
2.	Establish a herd health protocol e.g. through using a herd health plan.
3.	Maintain regular contact with your vet and discuss disease prevention and herd health status.
4.	Isolate sick animals and carry out testing to monitor their disease status.
5.	Vaccinate to control diseases already on the farm.
6.	Implement rapid culling of persistently infected animals where it is appropriate for the disease.
7.	Maintain a closed herd.
8.	Verify the disease status of bought in animals by consulting with the seller farmer’s vet.
9.	Verify the disease status of bought in animals by asking the seller farmer.
10.	Verify the disease status of bought in animals by viewing accredited test results.
11.	Isolate new animals after purchasing for a minimum of three weeks.
12.	Test new animals bought onto the farm to assess their disease status.
13.	Avoid hiring bulls.
14.	Prevent nose to nose contact with neighbouring animals by maintaining adequate fencing.
15.	Do not graze animals on grass spread with slurry for at least 6 weeks.
16.	Do not spread fields with imported slurry.
17.	Prevent cattle having access to common waterways.
18.	Isolate and test young stock re-entering the farm after being housed off-site.
19.	Isolate animals returning from livestock shows.
20.	Prevent wildlife accessing housing sheds and food supplies.
21.	Maintain a pest control regime.
22.	Minimise the number of visitors entering the farm.
23.	Ensure that visitors’ shoes, clothing and vehicles are clean when entering the farm.
24.	Have a separate area on the farm for incoming vehicles and stock.
25.	Avoid equipment sharing between farms.
26.	Disinfect borrowed vehicles and equipment before and after use.
27.	Ensure contractors use clean equipment on the farm.
28.	Maintain good hygiene in the housing, yard, parlour and other farm areas.
29.	Wash hands and disinfect clothing when going between herds on the farm.
30.	Implement a programme of preventive vaccination for diseases not already on the farm.

Table 2 Example BWS

Please pick the most effective and the least effective measure for stopping the spread of disease onto and within the farm, in the absence of any practical constraints to implementing them.		
Most effective		Least effective
◻	Ensure that visitors' shoes, clothing and vehicles are clean when entering the farm.	◻
◻	Avoid equipment sharing between farms.	◻
◻	Maintain a closed herd.	◻
◻	Monitor and record the herd health status through regular disease testing.	◻
◻	Minimise the number of visitors entering the farm	◻

Table 3 Descriptive statistics of respondents

Respondent group Farmer	Total number 16	Region (n) England NE = 1 England NW = 3 England Central = 4 England SE = 4 England SW = 2 Northern Ireland = 0 Scotland = 1 Wales = 1	Age (n) Under 30 = 2 30-40 = 1 40-50 = 4 50-60 = 6 > 60 = 3	Closed herd (n) – 11 Open herd with biosecurity measures (n) – 5	Year round housing (n) – 2 Seasonal housing and grazing (n) – 12 Year round grazing (n) – 2
Respondent group Vet	Total number 28	Region (n) England NE = 2 England NW = 8 England Central = 2 England SE = 2 England SW = 10 Northern Ireland = 0 Scotland = 2 Wales = 2	Median number of years practicing as a vet = 19 years. Interquartile range = 13-30 years.	Median % time spent on dairy veterinary work = 85% Interquartile range = 79-90%	Median % time on dairy farms spent in disease prevention advisory role = 25% Interquartile range = 20-40%
Respondent group Other	Total number 16	Profession (n) Industry = 7 Qualified veterinary surgeon = 8 Academia = 3 Government = 4 Consultancy = 5 Other =1 (dairy farmer)			

Table 4 Effectiveness and practicality scores for each measure

The symbols [a]* show that the measure's effectiveness score was significantly higher ($p \leq 0.05$) than the practicality score. The symbol [b]* shows that the measure's practicality score was significantly higher ($p \leq 0.05$) than the effectiveness score.

Set of measures	Item number	Mean effectiveness scores	95% CI	Mean practicality scores	95% CI
Knowledge, planning and vet involvement	1.	5.55	4.82 - 6.28	4.017	3.36 - 4.68
	2.	5.71	4.81 - 6.61	6.20	5.51 - 6.89
	3.	6.03	5.23 - 6.85	7.93[b]*	7.46 - 8.39
	30.	2.97	5.23 - 6.85	2.24	1.55 - 2.93
Quarantine and treatment	4.	3.27	2.67 - 3.87	2.30	1.73 - 2.88
	5.	4.91	4.18 - 5.65	5.74	4.99 - 6.50
	6.	6.28	5.52 - 7.03	4.27	3.52 - 5.03
Buying in animals	7.	8.89[a]*	8.20 - 9.57	2.42	1.56 - 3.29
	8.	4.71	3.86 - 5.57	3.47	2.80 - 4.13
	9.	0.54	0.25 - 0.84	4.88	4.01 - 5.76
	10.	6.13[a]*	5.44 - 6.82	3.87	3.09 - 4.66
	11.	4.49[a]*	3.73 - 5.25	0.77	0.49 - 1.06
	12.	7.03[a]*	6.25 - 7.81	3.85	3.26 - 4.44
	13.	4.66	3.84 - 5.48	6.73	5.99 - 7.48
Grazing livestock	14.	7.14[a]*	6.68 - 7.59	2.25	1.74 - 2.76
	15.	0.46	0.37 - 0.55	3.23	2.50 - 3.96
	16.	2.58	2.07 - 3.09	7.28[b]*	6.60 - 7.96
	17.	1.21	0.84 - 1.57	1.32	0.83 - 1.81
Animals re-entering farm	18.	3.58[a]*	2.95 - 4.20	1.09	0.62 - 1.57
	19.	1.81	1.32 - 2.30	1.03	0.85 - 1.21
Pest control	20.	2.93	2.23 - 3.63	0.41	0.07 - 0.75
	21.	0.63	0.28 - 0.99	3.04	2.50 - 3.59
Visitors	22.	0.16	0.09 - 0.23	3.38	2.59 - 4.17
	23.	1.07	0.63 - 1.51	3.13	2.33 - 3.93
	24.	1.63	1.03 - 2.22	0.87	0.56 - 1.17
Equipment	25.	0.58	0.43 - 0.74	2.60	1.97 - 3.22
	26.	0.64	0.49 - 0.79	2.19	1.66 - 2.72
	27.	0.72	0.53 - 0.91	1.69	1.11 - 2.26
Hygiene	28.	3.01	2.35 - 3.67	4.39	3.65 - 5.14
	29.	0.67	0.36 - 0.98	3.42	2.63 - 4.22

767 **Shortall Figure 1**

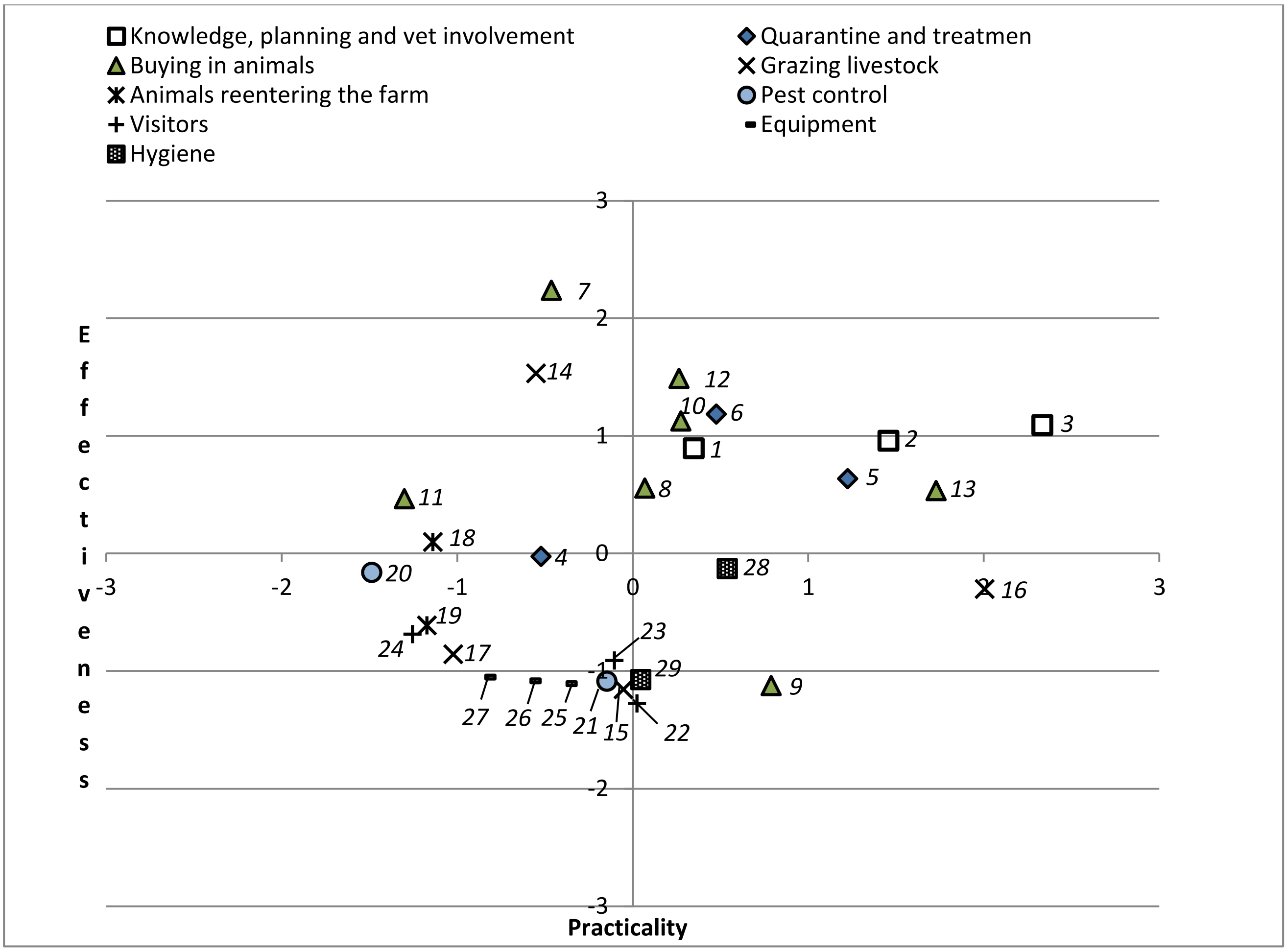

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Figure 1 Zero centred scatter plot of effectiveness and practicality scores by measure set. Practicality scores are on the X axis, effectiveness scores are on the Y axis. Refer to table 1 for list of biosecurity measures by number. Symbols in legend indicate groups of measures.

Shortall Figure 2

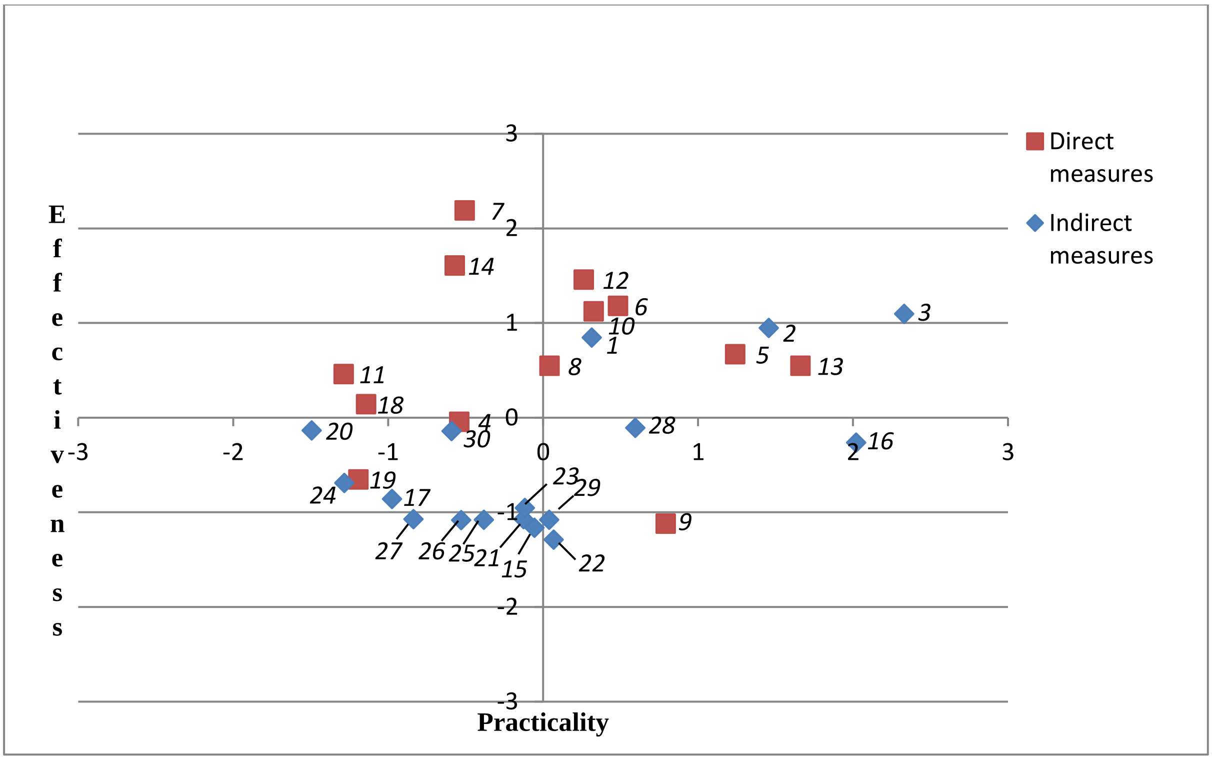

Figure 2 Zero-centred scatter plot of effectiveness and practicality scores as direct or indirect measures. Practicality scores are on the X axis, effectiveness scores are on the Y axis. Refer to table 1 for list of biosecurity measures by number.

Table 5 Heterogeneity within scores. The letter F stands for farmer respondent group, O stands for other respondent group and V stands for vet respondent group. The symbols F>O means that the farmer respondent group scored that measure as significantly ($P < 0.05$) more effective than the other respondent group, and likewise for vet and other groups.

Measure No.	Heterogeneity in effectiveness scores	Significant differences between respondent groups' effectiveness scores	Heterogeneity in practicality scores	Significant differences between respondent groups' practicality scores
1	No	-	Yes	-
2	Yes	F>O	No	-
3	Yes	V>F	No	-
4	Yes	V>F	Yes	-
5	Yes	-	Yes	V>F
6	No	-	Yes	F>V, F>O
7	No	-	Yes	F>V, F>O
8	Yes	O>F	Yes	-
9	No	-	Yes	V>F, V>O
10	No	-	Yes	-
11	Yes	-	No	-
12	No	-	Yes	V>O
13	Yes	V>O	No	-
14	No	-	Yes	F>V, F>O
15	No	-	Yes	V>F, V>O
16	Yes	-	No	-
17	No	-	No	-
18	Yes	-	No	-
19	Yes	-	No	-
20	Yes	F>V	No	-
21	No	-	Yes	-
22	No	-	Yes	O>F
23	No	-	Yes	-
24	Yes	-	No	-
25	No	-	Yes	-
26	No	-	Yes	-
27	No	-	Yes	O>F
28	Yes	-	Yes	O>F
29	No	-	Yes	-
30	Yes	V>F , V>0	No	-