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Assessment of path choices on a country walk using a virtual environment

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Abstract

Virtual environments can provide landscape researchers new opportunities to explore aspects of landscape perception and response. A virtual environment requires a detailed 3D model of a place and the use of a high performance computer to allow people to explore it interactively. As with any new experimental tool, we should first establish the validity of the technique. This paper describes the process of model building for a section of the Dee valley in northeast Scotland, the development of software to support interactive exploration, and an experiment which was designed to answer some primary questions about validity and some secondary ones about local landscape preferences. The findings were encouraging for the further use of virtual environments and showed that people made choices in the virtual environment which fitted their stated preferences and were different from the choices other subjects made on the basis of still images. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Bishop et al. (2000) describe the rationale for using virtual environments to take an experiential approach to landscape assessment. Zube et al. (1982) defined the experiential paradigm as one that involves the monitoring of peoples' behaviour rather than asking them to complete a questionnaire, an approach which Daniel and Vining (1983) referred to as phenomenological. An experiential study could include analysis of poetry or paintings about the environment, the way private or public parklands have been developed, or route choices when out for a walk or a drive. The most accessible of these options, and the easiest to translate into a virtual environment, is the choice of a route when out for a walk or a drive. In addition to learning more about landscape appreciation and preferences, the monitoring of choices people make in relation to movement can generate some of the behavioural rules necessary for an autonomous agent-based approach to landscape management (Bishop and Gimblett, 2000).

Molnar (1986) argued the importance of free interactive movement in landscape design assessment.

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However, at that time Molnar was restricted to wireframe object representation in order to get full interactivity, whereas today even modest hardware and software resources can be used to achieve a landscape representation which is reasonably realistic and interactive. The use of a virtual environment model can provide an opportunity to explore places that are otherwise inaccessible (i.e. in the past or the future), and so provide a visual decision support capability for landscape management (Kraak et al., 1995; Raper et al., 1998). Although conventional maps can contain valuable data on the landscape, a greater degree of intuitive understanding is possible when imagery and data are provided in more than two dimensions (Neves and Camara, 1999), thus virtual environments can have the effect of widening access to information pertinent to a process of decision-making (Daniel, 1992).

The procedural issues and validity of extending the role of the virtual environment in decision support from one of landscape visualisation to include evaluation of the landscape have not yet been widely addressed. The objectives of the experiment reported in this paper were first, to learn about the validity of a method for incorporating free interactive movement in landscape design assessment and second, to explore the factors which influence movement choice in the countryside.

The experimental process involved the following:

1. The development of a detailed 3D digital model (including terrain, vegetation and buildings) of a selected environment.
2. The development of software for assigning viewpoints and paths within a virtual environment, with which real-time imagery of the environment could be presented to the user as they move along the chosen paths and their choices recorded.
3. The definition of specific paths and choice points within the environment.
4. The incorporation of adjustments to the modelled environment for specific experimental purposes (e.g. introducing new stands of vegetation).
5. The testing of subjects in the virtual environment and recording their choice of paths and the completion of a brief questionnaire.
6. An analysis of the path choices and questionnaire responses.

Each of these steps is described in more detail below.

2. Database development

2.1. Study area

The study area is the upper Dee valley, west of the village of Braemar, in the Cairngorm Mountains of Scotland (Fig. 1). The Cairngorm Mountains, extending up to 1296 m above sea level, are the subject of a number of initiatives aimed at assessing the resource potential of the area and its current and future management (e.g. Cairngorms Partnership, 1999a,b). They are the focus of interest for conservation, recreation, and agricultural activities in their broadest sense. The study site is located within the area that is also the subject of prospective legislation under which it will become a National Park.

The future management of the study area involves all aspects of the natural environment and, as the most extensive example of boreal forest in Scotland, the forests of the Cairngorms are particularly significant. The woodlands of Upper Deeside include the highest densities of ancient semi-natural woodland in Scotland. Indeed, the guidelines for sustainable forestry in the United Kingdom (Forestry Commission, 1998), state that because of the high value placed upon woodlands in many landscapes the impact of their management should take account of different stages of their growth, viewing distance, direction and scale. Therefore, woodland comprises a significant element of the virtual environment developed in this study.

New methods of evaluating the content of the landscape, and people's preferences towards it, can contribute to an understanding of one aspect of the overall management requirements of this type of area. Due to the significant interest in the area a considerable amount of spatial data has been compiled in a digital form. This provided the raw materials for the development of a visual simulation model of sufficient detail and realism to be used as a virtual environment.

2.2. Topographic data

A 50 m resolution digital elevation model (DEM) covers the area, within which the view catchment lies, and a 5 m DEM (derived by digital photogrammetric

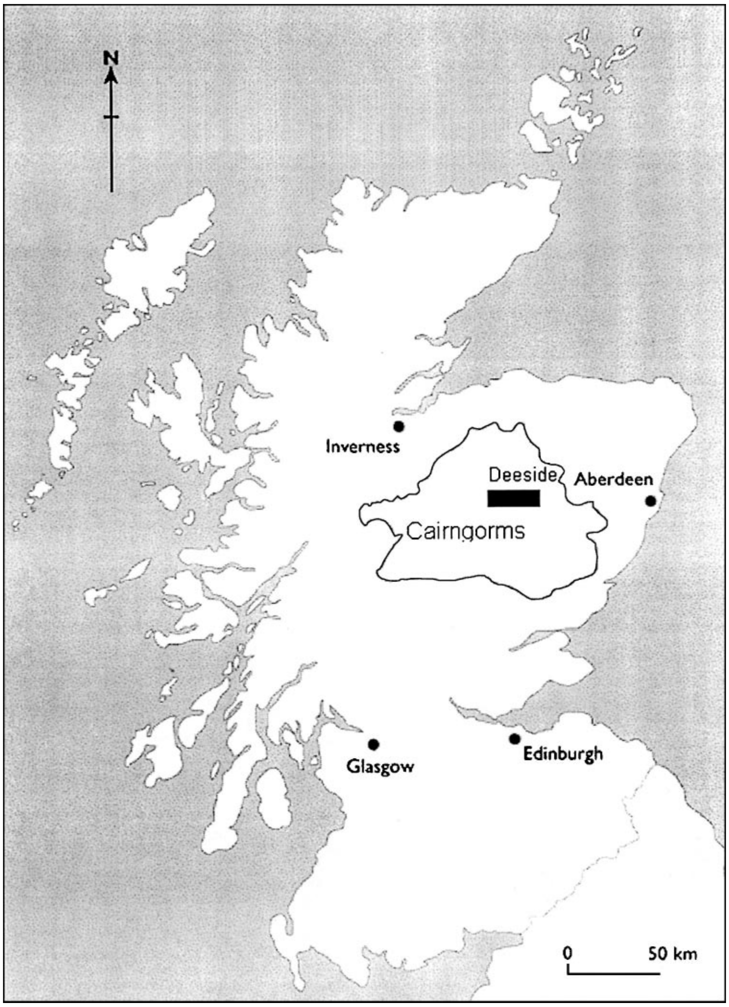

Fig. 1. Location of study area in upper Deeside.

techniques) was available for the valley floor and the adjacent valley sides.

A key factor in database design was to retain a sufficiently high level of detail for validity of the visual image but to constrain the resolution of the data to enable effective interactivity with the software and hardware configuration. Therefore, following some initial tests the two original DEMs were resampled to lower resolutions. The 50 m DEM for the area surrounding the study valley was resampled to $200\,m \times 200\,m$ and the DEM for the valley bottom was resampled to $20\,m \times 20\,m$.

The DEM at the higher resolution was inserted into that at the lower resolution, to provide a surface of greater detail within the core of the study area but also a broader topographic context for the visualisation of the landscape. The joining of the two DEMs was undertaken in such a way as to ensure that any mismatch in their intersection was hidden from view from the valley bottom, and thus from an observer within the virtual environment. The higher resolution data, where it existed, took precedence.

2.3. Textural data

A high resolution (1 m), true colour, digital orthophotograph was available for the inner valley of the study area which was draped across the DEM surface.

No image-based textures were used for the surrounding areas, instead colours were allocated for the outer DEM-based upon terrain elevation, using colours chosen from the orthophotograph. These colours were chosen to represent land cover types which are common to the area such as forest, heather, rock and also snow.

2.4. Feature data

Models of selected features were added to the basic topographic and textural framework of the study area. These models predominantly comprised trees or shrubs of different types and a building. The distribution of the vegetation features in the inner valley was taken from an existing digital land cover data set, the Land Cover of Scotland, 1988 (Macaulay Land Use Research Institute: MLURI, 1993). The land cover types present in the valley, and their interpretation in terms of tree species, heights and densities, are given in Table 1. The tree features were represented by two (double-sided) vertical planes at right angles to one another. Onto these surfaces were mapped textures of species appropriate to the area taken from terrestrial digital photographs taken in the valley or collected in earlier studies (Wherrett, 1998). Image processing software (SGIs imgview) was used to define the corresponding transparency maps.

2.5. Creation of virtual environment

In-house software used the DEM and the land cover data as inputs to separate land cover types into different groups within the Alias/Wavefront '.obj' format (Wavefront_Technologies, 1993). A further in-house software package was used to create separate '.obj' files in which trees were located within polygons for appropriate land cover types, but which introduced a random offset of up to a quarter of a cell in x and y to prevent unnatural alignment of the trees, while retaining the approximately correct elevation values. The heights of the trees were also randomly varied by up to 10% either side of the preset values given in Table 1. Two simple buildings were included in the virtual environment, the dimensions and layout of which were specified using a basic text editor, and with textures taken from a photograph of a cottage considered typical of the area. The sky was constructed using a truncated sphere, onto which a photographic image of a sky scene was projected.

When the separate '.obj' files had been developed for each of the DEMs, the vegetation groups, the buildings and the sky, they were merged into a single file in the Alias/Wavefront Advanced Visualizer software (Wavefront_Technologies, 1993). The completed database contained 88,000 polygons and 6 MB of imagery as textures.

3. Virtual environment

3.1. Software issues

The software used to navigate the virtual environment was developed using the IRIS Performer graphics library (Rolf and Helman, 1994). A scene graph (an internal representation of the virtual environment) is build by the Performer loader which can read a variety of 3D model formats (such as, .dxf, .obj and .flt). Having built the scene graph, a 2D map of the area is presented to help the developer specify viewpoints and pathways between them. As these paths are straight lines, several viewpoints may need to be specified for a walk to follow a 'curved' path. At each viewpoint the developer can specify up to three other points to which the subject can move. The points, and path specifications, are kept in a text file which can subsequently be edited.

The high performance graphics hardware and software can provide real time movement through

Table 1
Vegetation types and the species, density and height values used in model development

Vegetation classification	Species, densities (on 20 m grid) and height values
Pine plantation	Young Scots pine, 90% density, 15 m average height
Low density woodland	Deciduous, 5%, 20 m, spruce, 5%, 27 m, fir, 5%, 27 m
High density woodland	Deciduous, 20%, 17 m, spruce, 20%, 22 m, fir, 20%, 22 m

complex data sets, however, uninhibited movement is not necessarily the most appropriate mode for testing personal movement choices in the environment. A more constrained set of options may prove better because movements in the real world are normally constrained, e.g. by path systems, traffic flow, slope, vegetation, etc.

Unconstrained movement options provide a much more complex set of results for analysis, and previous experience suggests that a subject in an unconstrained environment is easily disoriented unless the graphic performance is at least 30 frames per second, the level of realism is very high and the virtual environment is large enough that the subject would not reach the edge in the time given. The design and performance criteria for virtual environments have also been explored further by Wann and Mon-Williams (1996). Therefore, the software has been designed to utilise fixed view points and constrained pathways as a basis for experimentation on landscape use and the reactions of people to its contents.

3.2. Path definition

Fig. 2 shows the defined paths and choice points used in the experiment reported upon in this paper. The paths were only defined for routes along the valley bottom for two reasons. Firstly, limiting the pathways to the valley bottom reduced the extent of the geographical area for which detailed topographic, textural and feature-based details would be required. Otherwise, routes across hilltops (although possibly more credible in the context of the movements of some people) would enable views across to other hill slopes and into neighbouring valleys. Secondly, the software interpolates linearly between defined viewpoints. Movement over undulating terrain therefore requires definition of many path definition points to ensure that the viewpoint stays at an approximately constant height above the terrain. The Performer environment would allow collision detection to be employed so that a constant elevation is maintained automatically (drive mode) but this approximately doubles the screen refresh time. Tests on the experimental database showed a refresh rate of approximately 7 frames per second on an SGI Onyx Reality Engine and a frame rate any slower than this would probably have had detrimental effects on the efficacy of the choice experiment to follow.

Further design decisions involved the overall path length, the distribution of choice points and the speed of movement between choice points. A time limit of

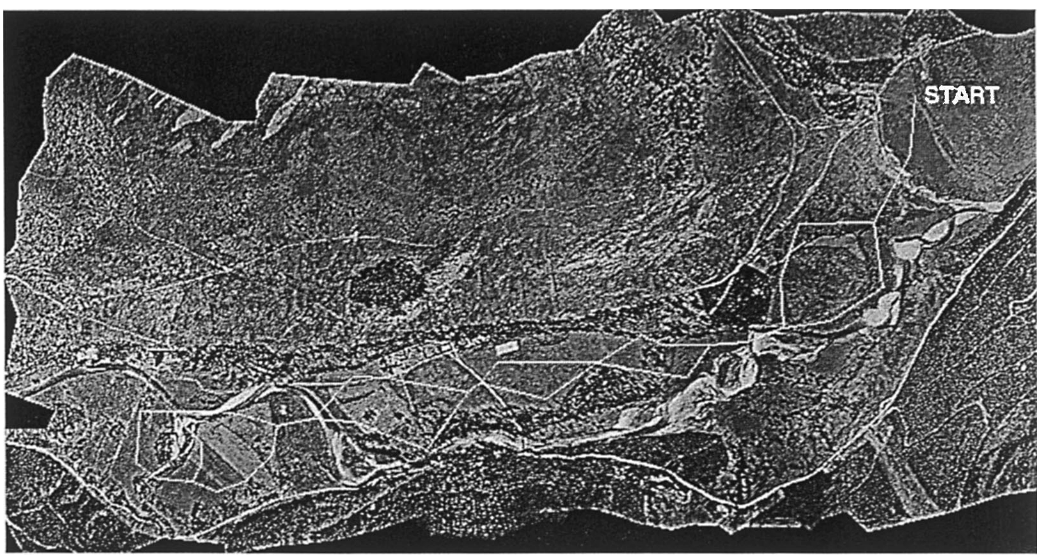

Fig. 2. Participants were shown this diagram of the path configuration. The 'walk' began at 'START' and proceeded automatically to the first choice point. After selection subjects travelled along the left or right path option before joining the main path again and proceeding to the next choice point.

15 min was imposed on the experiment, which was seen as the probable limit of subject's concentration on the task, and the amount of time they would be willing to give to the experiment. Using the full length of the database for an outward and return trip gave a full 'walk' extent of approximately 6 km. This corresponded to a ground speed of 24 km/h which is more akin to the speed of a bicycle tour than a leisurely walk. However, subjects were asked to consider that they were *walking* in the country.

The frequency of choice points and angle of view of the choices presented at each point were determined by the geographical separation necessary to give different environmental views. We also wanted people to move in a logical manner along the valley bottom, essentially in the one direction, until turning to head back to the start. This led to five choice points along a 2 km length. After each choice point the paths separated for a distance and then rejoined. The first four rejoining points became the four choice points for the return journey. In order to maintain interest and attention through the turn in the middle of the walk an additional path choice was introduced for those going in either direction around the curve. This made a total of 10 choice points for each subject.

3.3. Environmental adjustments

One landscape management issue of considerable interest in this geographical area is the way in which people react to forest management and structure. Much of the area includes young pine plantations, and forest strategies for the future will likely lead to an increase in such woodland by natural regeneration or direct planting and management (Cairngorms Partnership, 1999a). The semi-natural vegetation, such as heather moorland, may also be classified as having low and medium density scattered woodland (Hester et al., 1996). Therefore, these further three groupings of woodland cover were introduced along the paths to enable specific comparisons to be made of people's preferences with respect to different patterns of woodland that may be found in landscapes in the Scottish highlands. The other variable used in positioning the new woodlands was whether they were adjacent to the path on only one side or on both sides. Fig. 3 shows the distribution of the woodland stands in the study area.

4. Subject testing

The subjects used in the choice experiment were all employees of the Macaulay Land Use Research Institute in Aberdeen, Scotland. No attempt was made to get a representative sample: a general call was made for volunteers and 42 subjects participated. They were seated at the SGI computer with 530 mm (21″) screen. They were given a set of instructions by the survey manager, and also shown a map of the area (Table 2 and Fig. 2):

Following any questions for clarification, subjects were left alone in the room. They saw a view along the path as they moved forward. When they reach a choice

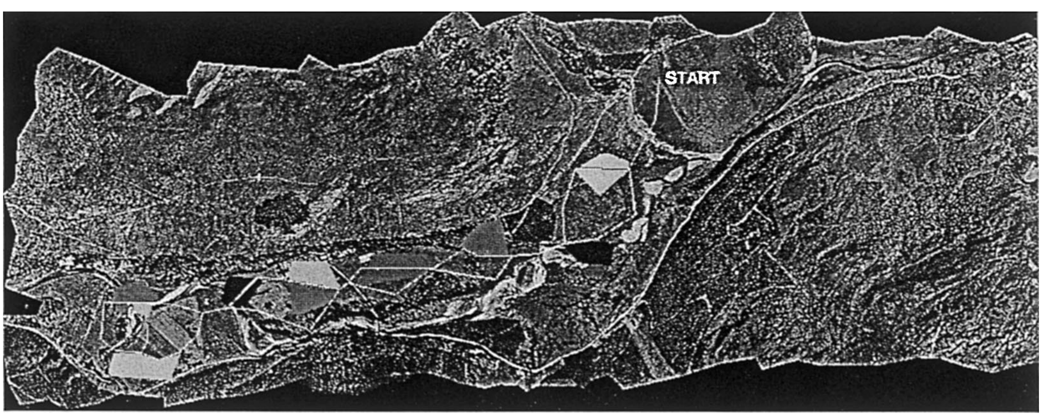

Fig. 3. New vegetation areas introduced into the data set. Low density woodland (white), high density woodland (black) and young pine plantation (pale grey).

Table 2
Instructions to study participants

Thank-you for agreeing to take part in this experiment
This is not a study about a particular landscape but about the process of using a computer-based virtual environment to study the landscape choices which people make
You will be asked to take a virtual walk through an area of Scottish countryside. You may recognise the environment which has been used as the basis for the experiment. However, this should not influence your choices
The accompanying map shows how they are several alternative routes that can be taken in 'walking' up the valley and back down again
The rate of movement will be rather quicker than normal walking speed but you should try to think about the experience as if you are out for a country walk. Look around, notice the different elements you find in the landscape. If you spot any trees that seem to be floating try to disregard these. You may also brush against a few trees during the walk
At the bottom of the screen, in the smaller window, are views from further along the track. Please concentrate your attention on the large window until such time as the motion stops and you hear a small 'beep'. This means that you have reached a choice point — *you can select either the track to the left or the track to the right*. In the lower window you see the view along each of these tracks from the choice point. You may wish at this stage to use these windows to help you to decide which path to take
The choice is made by pressing either the left or the right mouse button. *The left button selects the left path and the right button the right path.* Note that the choice is not influenced by the position of the cursor on the screen. I suggest that you do not keep a hand on the mouse but just use the buttons after you have made your path selection
When you are ready to start you simply push any mouse button. The computer will take you from the start point to the first choice point. Enjoy the walk

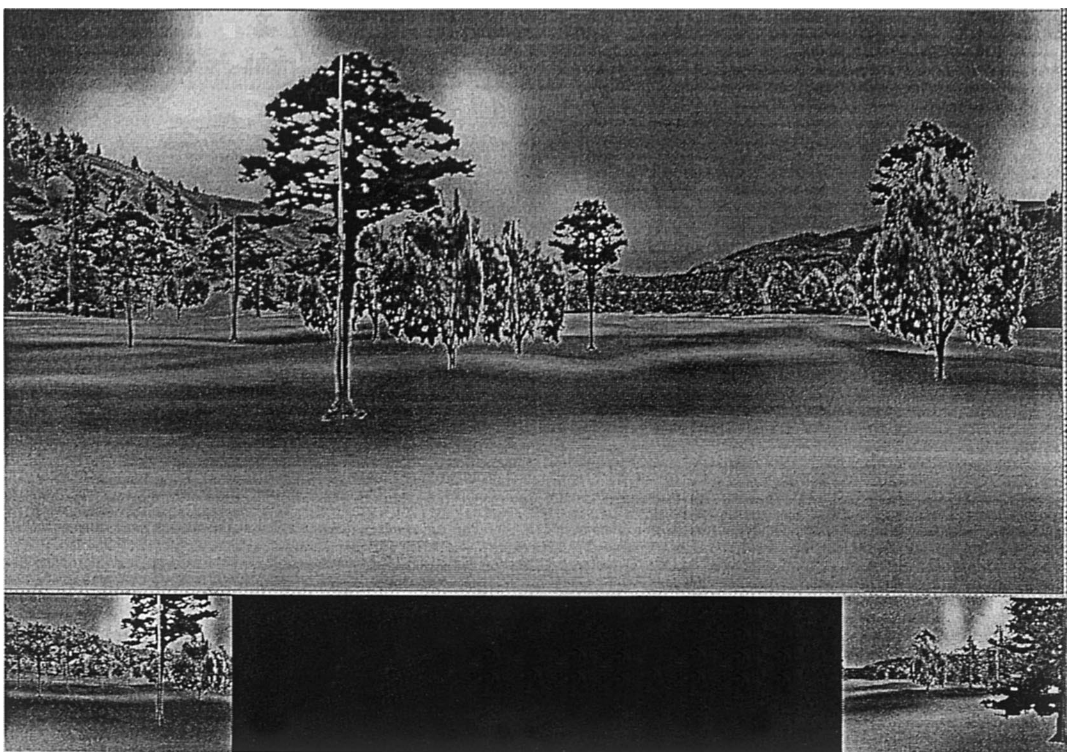

Fig. 4. View of the screen when subjects reached a choice point. The small images were an additional guide to the view along each path. Between choice points subjects saw only the large image, which was updated about 7 times per second.

point two smaller views appeared in the lower left and right corners of the screen (Fig. 4) representing the views directly along the optional paths. Subjects' choices were monitored and recorded from a remote computer and after the last choice point they were asked to complete a short questionnaire.

5. Follow-up test

In considering the validity of the process employed in the use of a virtual environment for assessing preferences in path choices it is worth considering whether the same result would be achieved by asking people to choose between two still images taken at the choice point. To test this possibility a survey was distributed via the Internet with the views along left and right paths side-by-side. Forty-one people, mostly different from the interactive assessment group, indicated their preference for each pair of images.

6. Analysis

In relation to the primary objective of establishing validity for the process, a small number of basic response characteristics needed to be met. For a first level of validity we required that:

1. the choices of route would be other than random, i.e. clear path preferences would be expressed;
2. responses would be separable into identifiable groups with distinct preferences;
3. the preferences shown during the walk would match the preference stated in the accompanying questionnaire.

A χ^2-test was used on the path choices and it was found that the preference for one path over the other, when the whole sample was considered, was significant ($P < 0.001$) at three of the 10 choice points (Table 3). This showed that the simulated environment was sufficiently differentiated between views for people to make reasoned judgements about their next movement.

At those points where the number of choices right and left were approximately equal, two possible explanations were considered valid: (1) the two directions were sufficiently similar that no-one had a strong preference for either direction, or (2) that half the people had a clear preference for one direction while the other half had a clear preference for the other, i.e. that sub-groups with different preferences existed within the sample population. Inspection of the imagery at these points suggested that the second explanation was more likely, since the views from these points were quite dissimilar in terms of landscape morphology and tree density. We chose to use cluster analysis to clarify this point.

Table 3
Results at each choice point. The difference between numbers of left and right choices is significant (χ^2) at 3 of the choice points

Turn	#L	#R	%L	%R	Significant (P)
1	22	20	52	48	0.758
2	20	22	48	52	0.758
3	33	9	79	21	0.000[a]
4	33	9	79	21	0.000[a]
5	17	25	40	60	0.217
6A	9	16	36	64	0.090
6B	5	12	29	71	0.162
7	21	21	50	50	1.000
8	19	23	45	55	0.537
9	20	22	48	52	0.758
10	7	35	17	83	0.000[a]

[a] Significant at $P < 0.001$.

There were two sets of indicators on which to undertake cluster analysis to determine if identifiable sub-groups existed. Clustering could be done on either the stated preferences (attractors and detractors in the questionnaire), or on the actual decisions taken. These were open ended questions but similar factors appeared regularly and these were classified as trees, dense trees, conifers, hills, open areas, buildings and edges. These were coded as 0 if not mentioned, 1 if mentioned as an attractor or -1 if mentioned as something being avoided (a detractor). Before the cluster analysis the five participants who gave no stated preference factors or who answered that their choices in the VE were essentially random were eliminated. K-means cluster analysis (Hartigan, 1975) was then undertaken on 37 sets of subject responses. The separation into sub-groups based on stated preferences (Table 4) appears to distinguish between those who (1) like to be in the trees but are not fond of either hills or open areas, (2) like the trees (but not plantations) and the hills but dislike the

Table 4
Cluster analysis based on stated attractors and detractors in the questionnaire

	Final cluster centres		
	1	2	3
Trees	0.92	0.83	0.23
Densetree	0.08	0.00	−0.54
Conifers	−0.17	−0.75	−0.46
Hill	−0.25	0.83	0.77
Open	−0.58	−0.75	0.62
Building	0.33	0.33	0.15
Edges	0.08	0.08	0.00

open areas, and (3) like open hills and dislike dense plantations.

A K-means cluster (Table 5) was also performed on the same 37 participants using their actual choices at the common choice points (i.e. all except 6A and 6B).

The clusters based on stated preference and the cluster based on behaviour should be similar since the decisions should be a direct expression of stated preferences. Table 6 shows the relationship between the cluster groups. The choice points which best defined the clusters (choices 2, 5, 8 and 9) were examined and the weightings on the clusters at these points seemed to confirm the match between clusters. Although, as a result of the small sample size, the result is not definitive ($p \sim 0.35$) the pattern is enough to suggest that the simulated walk is sufficiently realistic for people's preferences to emerge. In the questionnaire responses some people indicated that they tried to go a different route on the return journey than on the outward journey. This would tend to reduce agreement between preferences and performance.

Table 5
Cluster analysis based on the actual decisions made in the VE. Choice points 6A and 6B were not used as they were not visited by all respondents

Choice point	Final cluster centres		
	1	2	3
1	−0.16	0.67	0.00
2	−0.68	1.00	0.33
3	0.68	0.00	0.67
4	0.47	0.67	0.83
5	0.37	−1.00	−0.83
7	−0.05	0.67	0.00
8	−0.79	0.67	0.83
9	−0.47	−1.00	1.00
10	−0.89	−0.67	−0.50

Table 6
A comparison of the two clustering procedures[a]

	Cluster by questionnaire			Total
	1	2	3	
Cluster by choice				
1	9	5	5	19
2	1	3	2	6
3	2	4	6	12
Total	12	12	13	37

[a] The table and graph show only moderate correspondence between the groups. The (χ^2) significance is ∼0.35. Five subjects were eliminated from the cluster analysis because either they did not answer the question on choice motivation or they reported their choices to be essentially random. Choice points 6A and 6B were also not used as they were not visited by all respondents.

The subjects were also asked about the extent to which they felt they were making a deliberate decision in an environment like the real world. The results are shown in Fig. 5. On a 7 point scale (0 being not like the real world/deliberate decisions to 6 being very like the real world/essentially random), the average scores were 3.5 for 'similar decisions to the real world' and 2.2 for 'deliberate decisions versus essentially random choices'. A value of 3.5 suggests that the current experimental approach will require further refinement to ensure that the decisions being made are clearly associated with those of a 'real world' environment. The static choice points had a realism score of 3.3 and a deliberate choice score of 2.5, similar to, but slightly less convincing than, the scores from the virtual reality experiment.

In the follow-up test on the Internet there were two instances, among the 10 choice points, where the percentage choosing left changed by more than 20% between media. In both cases the swing can be explained by the extra information available to the 'moving' viewer compared to the 'still' viewer (Table 7). Approaching the first choice point the moving person could see on their right a mixed woodland and on their left a comparatively open area. At the choice point the view to the right included two

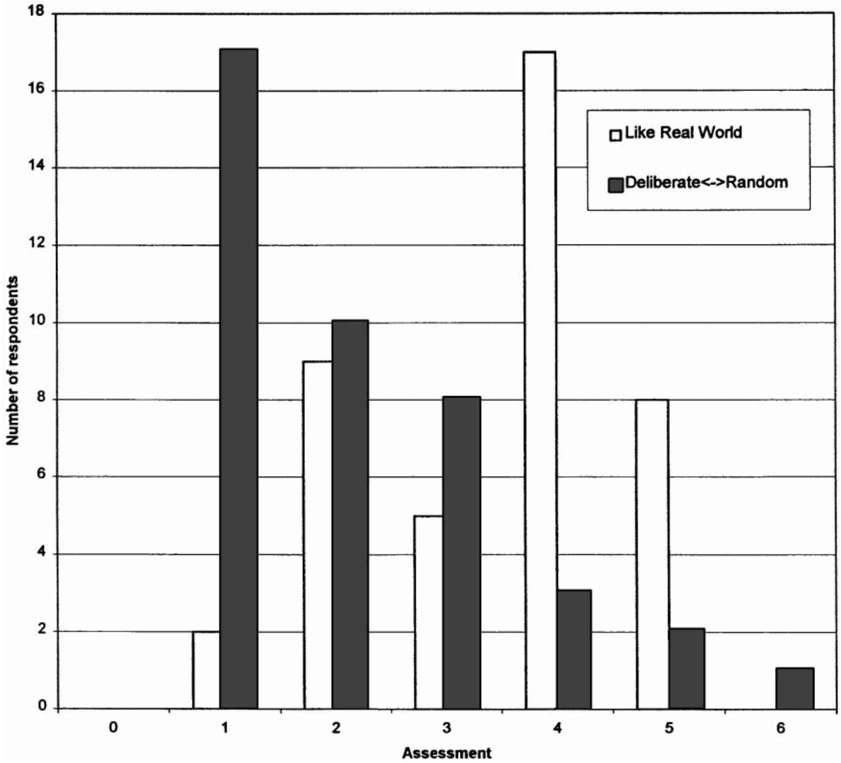

Fig. 5. The distribution of responses to the questions: (a) to what extend was the choice process like the real world (scale 0–6)? (b) to what extent were your choices random (6) rather than deliberate (0)?

Table 7
A comparison of choices made by moving and still observers

Choice point	Subjects in interactive virtual environment (42 respondents)		Subjects seeing only still images of path choices (41 Internet respondents)	
	Percentage of turning left	Percentage of turning right	Percentage of turning left	Percentage of turning right
1	52	48	76	24
2	48	52	49	51
3	79	21	78	23
4	79	21	66	34
5	40	60	34	66
6A	36	64	83	17
6B	29	71	34	66
7	50	50	46	54
8	45	55	30	70
9	48	52	47	53
10	17	83	24	76

conifers very close to the camera and no other visible trees. The still viewer might therefore interpret this as dense pine forest rather than open mixed woodland. The second instance of a big swing appears to have a similar basis. In this case (point 6A) the moving viewer could see, before reaching the choice point, that the plantation of young pines was small and that more open land lay on the other side. The still viewer, on the other hand, did not have this information and might have assumed that the plantation extended over a large area.

Our secondary purpose was to gain some initial insight into the basis of people's preferences for walking within the Dee valley landscape. This may, or may not, be the same as their preferences for landscape views. As the cluster analysis based on the questionnaires showed people were split on some points and of similar mind on others. All groups were positive about trees but had negative views on the pine plantations, all were drawn (to a lesser extent) towards the houses — the effect of this variability in preference means that any further meaningful analysis of choices requires a larger number of choice points with much more structured variation in visual characteristics.

7. Discussion

The information provided by movement in the landscape is the most obvious, but not the only difference to the traditional landscape preference experiment based on paired comparison of images. When simple comparisons of images are made, or images rated in some manner, the order in which subjects see the images can be varied and order effects can be investigated. In the example described here, there was scope for variation in the order in which people encountered different vegetation groups. However, the environment had to be designed as a whole, and thus remain coherent from any vantage point available to a subject, and as a subject moved between environmental types they had to pass through boundaries or transition zones. Therefore, in the virtual world, as in the real world, abrupt changes of *landscape character* are not possible, although such abrupt changes may occur in the *land use*.

Other valid concerns about the process were raised in the comments section of the questionnaire and in a focus discussion after the completion of the experiment. These issues included:

- the expectation of a river in the valley bottom, partly based upon the path diagram (Figs. 2 and 3), and the search for such a river;
- the attraction of interesting cloud formations;
- the desire to move out of the valley bottom to get a better view;
- the fact that no tiredness was involved in the walk;
- the usual practice of pre-planning such a walk with maps, etc.;
- the lack of opportunity to consult a map during the journey.

Some of these issues can be addressed by more detailed modelling of the virtual environment. This might include the incorporation of additional features, more access to non-visual information, a wider-ranging network of paths, alternative experimental design or a relaxation of the constraints imposed to ensure the manageability of the experiment (e.g. 'freedom of movement'). Although there were no adverse comments on the quality of the visual representation, it was not 'photo-realistic', and improvements in this aspect of the model of the virtual environment would also be desirable. Providing subjects in a virtual environment access to a map — and an ability to control movement using the virtual map — has been tested by Bowman et al. (1998) and found to be advantageous in some circumstances.

The verisimilitude of the virtual environment is also dependent on some reminder that increased physical effort will be required if the uphill path is taken. The extension of the virtual environment to permit natural movement and physical effort depends upon haptic (physical or tactile) feedback. For example, to provide for more natural movement, Iwata and Fujii (1996) have developed a 'virtual perambulator'. This device, in which the user wears sliders on his/her feet but is constrained by a hoop around the waist, provides a sense of walking, or running, while fixed in position in the physical world. In our experiment one cluster group was negative about the prospect of walking into the hills. It seems likely that they would nevertheless prefer to have hills in the view. These people presumably like the hills but do not want to have to walk up them. Despite the absence of haptic feedback in this experiment, this result suggests that people were taking some account of the physical requirements of their choices.

Use of a single computer monitor is also not ideal. Humans have a field-of-view of approximately 200° (lateral) and 125° (vertical) when the head is still. This level of immersion should be paralleled in a virtual environment preferably by projection of the images onto a screen arrangement which permits something approaching this field-of-view. Curved and multiple screens systems are being installed in many research organisations and suitable software is available. Access to better display conditions should not be a problem in the near future.

In the experiment reported in this paper, the subjects were located in a room with other computers and their peripherals, and were therefore certainly not 'immersed' in the virtual environment. The impact of these conditions on the choices made by the subjects cannot be quantified, but it can be presumed that it is reflected in the answers to questionnaire on 'similarity to the real environment'.

8. Conclusion

The study clearly illustrated the potential of virtual environments as a basis for landscape evaluation through the experiential paradigm. The key results are clearly as would be hoped, and intuitively anticipated. It has been demonstrated that:

- people will make deliberate choices in the virtual environment;
- sub-groups within the subject population can be identified;
- the choices made appear to reflect stated preferences;
- movement through a virtual environment can produce different choices from people than exposure to still images only.

These results are not of major significance by themselves but they do permit us to take further steps along the path of development of virtual environments, and testing the validity of their application in landscape research. However, the final finding has potentially significant implications for the assessment of landscapes using still imagery, namely that the use of a virtual environment may communicate information about the context of the landscape which would lead to a different preference to an upcoming scene compared to the traditional approach of using still imagery. The broader applicability of the results will require further research. However, the availability of better data, faster computers, better display environments and haptic feedback will undoubtedly make the virtual environment experience more credible. This should, in turn, make observation of behaviour in simulated environments more reliable.

The vision of the landscape strategy for the Cairngorms area is a 'living landscape', recognising that it must support economic activity, as well as respecting the significance of natural and cultural heritage features. This implies a dynamic mixture of land uses including forestry, heather moorland, agriculture and wetlands, interspersed with country houses and villages. This research contributes towards the development of a landscape strategy in two ways. Firstly, virtual environments can be extended to include a coupling with other models, such as those of woodland growth, vegetation succession and animal movement through the landscape. Secondly, the technology lends itself to public communication about landscapes (past, present or future) and how management of the land can alter its function and appearance. The virtual environment can become a powerful tool for developing management regimes for achieving multiple objectives.

Over time, we can expect our knowledge of human responses to a variety of environmental conditions — urban parks, hazardous areas, fragile environments — to advance significantly. This should, in turn, lead to better decisions in many areas of environmental management.

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