A WIND-ANIMATED DIGITAL-TREE SHADOW

AS A MEANS OF IMPROVING

WINDOWLESS SPACES

by

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THESIS ABSTRACT

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Title: A Wind-Animated Digital-Tree Shadow as a Means of Improving Windowless Spaces

Windows provide building occupants with important physiological and psychological benefits but are absent from many indoor spaces. It is argued that most existing attempts at compensating for an absence of windows fall short because they lack either outdoor environmental information or sensory stimulation. A wind-animated digital-tree shadow was used to test this hypothesis.

The work concludes that the following strategies are likely to help most to compensate for an absence of windows: (1) establishing a live connection with the outdoors; (2) introducing controllable sensory variation into a space; (3) making such change a source of natural environmental information.

It is suggested that these approaches could be helpful used either separately or in combinations but that a live connection with the outdoors that introduces controllable naturally-generated change into a space would likely be most effective.

The video files that accompany this thesis show the digital shadow with wind and computer generated movement.

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For Ginger.

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CHAPTER I

INTRODUCTION

Windows have traditionally performed multiple roles for building occupants, including providing fresh air, daylight and information about the world outside. With the advent of artificial lighting and ventilating technologies in the early 20th century, however, it became possible to create habitable spaces without windows, to the point where some predicted that they would disappear entirely from buildings.[1] Clearly, that has not happened, but windowless spaces nonetheless exist in large numbers and a wide variety of forms today.

Although theoretically such spaces can be sufficiently lit and ventilated artificially, there is evidence that these may reduce both morale and productivity.[2] It has also been found that the occupants of such spaces tend to bring in significantly more pictures of outdoor scenes, plants, and televisions than those in rooms with windows, for example, apparently in an effort to reconnect themselves with the world outside. While these strategies have been shown to help morale and effectiveness to a limited degree, however, they have not been found to be effective replacements for windows.[3]

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[1] In 1936, for example, H.G. Wells wrote in his screenplay *Things to Come* that "the age of windows lasted four centuries." This scenario is discussed further in Anne Friedberg, *The Virtual Window: From Alberti to Microsoft. MIT Press, 2006.* 133-139.

[2] See Kelly Farley and Jennifer Veitch, *A Room with a View: A Review of the Effects of Windows on Work and Well-Being. Institute for Research in Construction, National Research Council of Canada, 2001*

[3] See Tina Bringslimark, Terry Hartig, and Grete G. Patil, "Adaptation to Windowlessness: Do Office Workers Compensate for a Lack of Visual Access to the Outdoors?" *Environment and Behavior* 43, no. 4 (2011): 469-

The research presented here stems from the belief that the key shortcoming of most existing ways of attempting to compensate for the absence of windows is that they lack the live sensory contact with the world outside normally provided by a window. More specifically, I believed that there were either one or two essential components missing from most existing approaches: either a live connection with the environment immediately outside, or varying sensory stimulation.

Based on this thesis, the study investigated the potential effectiveness of a hybrid natural/digital solution to these shortcomings. The approach examined uses outdoor electronic sensors to transmit live, wind-generated electronic data to a computer, where it is visually reproduced as a naturally-animated digital image projected onto an indoor surface. The moving digital image was designed to resemble the kind of natural tree shadows that sometimes animate rooms through real windows. The approach investigated, then, was based on digital representations of two natural phenomena: the shadow of a tree and live wind movement.[4]

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487. Also see Nancy J. Stone and Anthony J. English. "Task Type, Posters, and Workspace Color on Mood, Satisfaction, and Performance." *Journal of Environmental Psychology* 18, no. 2 (1998): 175-185.

[4] The choice of the tree form and wind-generated movement derived from two existing bodies of research suggesting that contact with nature in general, and with natural sensory variation in particular, acts to reduce stress and improve sustained alertness. The naturally-animated digital-tree shadow is not proposed as an *alternative* for real windows, but rather as a more effective remedy for spaces that already lack them. Wind was selected as the most frequently changing natural element. Others, such as sunlight or rainfall could also be used, and their manifestations would not necessarily need to be visual. Likewise, ambient sounds from the outdoor environment, both natural and artificial can easily be converted to changing visual information inside buildings.

Research Context

Over the past thirty years evidence from a range of disciplines has indicated that contact with nature has important psychological and physiological benefits for people. Well-known studies by the healthcare environments researcher Roger Ulrich and others, for example, have linked window views of nature to relief of stress, and the presence of indoor planting to improved productivity.[5] Our need for perceptible change in our surroundings in order to remain fully alert has also been consistently confirmed experimentally since studies on sensory restriction began in the early 1950s, and it is now generally accepted that unchanging environments lead to a rapid fall off in alertness, and eventually to fatigue and stress as we struggle to maintain concentration in under-stimulating conditions.[6]

The work of psychologists Rachel and Stephen Kaplan in the 1980s linked these two areas of research by suggesting that contact with nature serves to rest and restore attention and so reduce stress.[7] Their Attention Restoration Theory (ART) argued that many familiar patterns in nature, such as the movement of clouds or water for example, stimulate the senses without demanding our conscious attention. The Kaplans' work has focused mainly on the

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[5] See, for example, Roger Ulrich, "View through A Window May Influence Recovery." *Science* 224 (1984): 224-225; and Tina Bringslimark, Terry Hartig, and Grete G. Patil, "The Psychological Benefits of Indoor Plants: A Critical Review of the Experimental Literature." *Journal of Environmental Psychology 29, no. 4 (2009): 422-433.*

[6] See Donald O. Hebb, "Drives and the Conceptual Nervous System." *Psychological Review 62, no. 4 (1955): 243.*

[7] See Rachel Kaplan and Stephen Kaplan. *The Experience of Nature: A Psychological Perspective. Cambridge University Press, 1989*, and See Stephen Kaplan, "The Restorative Benefits of Nature: Toward an Integrative Framework." *Journal of Environmental Psychology* 15, no. 3 (1995): 169-182.

restorative effects of periods spent outdoors in nature, but one of the implications of their theory was that bringing natural movement indoors might help to sustain alertness without being consciously distracting.[8]

Evolutionary psychology attributes our continuing need for contact with both nature and change to the fact that human physiology developed largely outside in response to a constantly varying natural world. Many of us now spend the majority of our lives indoors, however, and as the environmental psychologist Judith Heerwagen has suggested, in our pursuit of 'optimal' indoor comfort conditions over the last fifty years this kind of natural variation has been virtually eliminated from many of the spaces where we now live and work:

> "Access to sensory diversity—change ... is a basic characteristic of the natural world. Sensory change is fundamental to perception…. Our indoor environments are largely devoid of sensory change, and deliberately so. Buildings are kept at constant temperatures and ventilation rates, the light from overhead fluorescent lights is the same day in and day out, ….Although many designers and researchers are beginning to express serious doubts about this state of affairs … there have been relatively few attempts to provide indoor environments that deliberately mimic sensory change as it exists in the natural world."[9]

Heerwagen suggests that windows provide four key benefits to building occupants: environmental information, sensory change, connection to the world outside, and restoration. She also points out that the increasing use of office cubicles "has essentially made

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[8] See, for example, Rachel Kaplan and Stephen Kaplan. "Adolescents and the Natural Environment: a Time Out?" In *Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations,* by Peter H. Kahn Jr, and Stephen R. Kellert, eds., 227-258. MIT Press, 2002.

[9] Judith Heerwagen, "The Psychological Aspects of Windows and Window Design." "The Psychological Aspects of Windows and Window Design." In *Proceedings of 21st Annual Conference of the Environmental Design Research Association. Oklahoma City: EDRA*, pp. 269-280. 1990.

the daytime world a windowless one for many people."[10] As many as half of those who work in high-rise office buildings, for example, do not have direct visual access to windows from their work place.[11]

Given a choice, most people show a clear preference for rooms with windows. Ninety percent of workers in windowless offices, for instance, said they were dissatisfied with their environment, and half thought that it was negatively affecting their work[12] When people are obliged to spend long periods in windowless spaces they often look for ways to compensate for the lack of contact with the outdoor world, the most common being potted plants and pictures of outdoor scenes. A survey of Norwegian office workers, for example, found that workers in windowless-offices were nearly five times more likely to bring plants into their workspaces than those with a window view, and more than three times more likely to have artificial images of nature in their work place.[13]

Several studies have found that the presence of indoor plants in a windowless room can reduce stress and increase productivity, but these improvements are modest in comparison to the effects of outdoor views of nature.[14] There could be several potential

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[10] Heerwagen, "The Psychological Aspects of Windows and Window Design," 273.

[11] See J. Edwards, "Daylighting as a Supplement to Electric Illumination." *BT Arch dissertation, Ryerson Polytechnical Institute, Toronto* (1978).

[12] See Theodorus Ruys, "Windowless offices." PhD diss., University of Washington., 1970.

[13] See Tina Bringslimark, Terry Hartig, and Grete G. Patil, "Adaptation to Windowlessness: Do Office Workers Compensate for a Lack of Visual Access to the Outdoors?" *Environment and Behavior* 43, no. 4 (2011): 469-487.

[14] Referring to indoor potted plants that are watered artificially by occupants.

reasons for this, but one of the most obvious differences is that indoor plants generally don't move in the way outdoor foliage does, meaning that they cannot provide the same kind of sensory variation.[15]

Moving television pictures, on the other hand, while they can certainly provide sensory variation, may be over-stimulating. The experimental psychologist Peter Kahn found that subjects in windowless rooms with a television had significantly higher average heart rates than those with a window for example,[16] and Roger Ulrich, who compared the effects of television images of natural and urban environments, found that patients' heart rates were actually lowest with the television turned off altogether.[17]

One of the key characteristics of television images is that they can effectively transport us to other places,[18] but this also means they generally lack the live contact to the world immediately outside that windows routinely provide. Closed-circuit television cameras can supply such local images, but the screen these are generally delivered on has a distancing

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[15] See Virginia Lohr, Caroline H.Pearson-Mims, and Georgia K. Goodwin, "Interior Plants May Improve Worker Productivity and Reduce Stress in A Windowless Environment." *Journal of Environmental Horticulture* 14 (1996): 97-100.

[16] Peter Kahn, et al. "A Plasma Display Window?—The Shifting Baseline Problem in a Technologically Mediated Natural World." *Journal of Environmental Psychology* 28, no. 2 (2008): 192-199.

[17] The natural images produced the next lowest heart rates, while the urban images and regular television footage generated the highest. See Roger S. Ulrich, Robert F. Simons, and Mark A. Miles, "Effects of Environmental Simulations and Television on Blood Donor Stress." *Journal of Architectural and Planning Research* 20, no. 1 (2003): 38-47.

[18] Projects like the "sky ceiling" by SkyV, for example, which installs LCD televisions on the ceiling and can display prerecorded cloud formations and wild life from anywhere in the world, often looking up through branches, or however their artists see best fit. From Peter Kahn, *Technological Nature: Adaptation and The Future of Human Life* MIT Press, 2011.

effect compared to a window, mainly due to a lack of parallax as an observer moves, which effectively tells them that the scene is not 'real.'[19] Peter Kahn, for example, found that people strongly preferred a window view to the same view seen through a closed-circuit television.[20] There are now several virtual window prototypes that can effectively simulate parallax effects, but these are expensive and, like televisions, tend to *disconnect* the observer from their immediate environment by displaying pre-recorded images from remote locations.[21]

Summary

Contact with nature has been found to have a range of psychological and physiological benefits for people; most notably it reduces stress, a major cause of many health and social problems. Perceptible change in our environment has likewise been shown to be essential to our maintaining alertness and attention, as well as reducing stress due to boredom.

Contact with both nature and change is generally limited inside buildings, but windows, especially those with natural views, have been shown to greatly reduce the negative consequences of our separation from the outside world. When these are absent, however,

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[19] The view through a window changes as an observer moves in relation to the frame. This parallax effect does not happen with television or computer screens.

[20] Peter H. Kahn Jr., Rachel L. Severson, and Jolina H. Ruckert. "The Human Relation with Nature and Technological Nature." *Current Directions in Psychological Science* 18, no. 1 (2009): 37-42.

[21] See, for example, Adrijan S. Radikovic, John J. Leggett, John Keyser, and Roger S. Ulrich. "Artificial Window View of Nature." In *CHI'05 extended abstracts on Human factors in computing systems*, pp. 1993-1996. ACM, 2005

there are currently few effective ways for occupants to remain in contact with the outdoors or obtain sufficient varying sensory stimulation.

The most common methods of attempting to compensate for a lack of windows, using indoor plants and pictures of outdoor scenes, fail to provide the sensory variation needed to maintain full alertness; while the kind of sensory change provided by televisions and virtual windows tends to distract from the immediate here and now, making them unsuitable to most working environments.

Hypothesis

Aside from light and air, the key resource supplied by windows would appear to be naturally varying sensory information from the environment immediately outside. Artificially projecting such change onto indoor surfaces, then, could be a more effective way of maintaining occupant morale and alertness in windowless spaces.

Since artificial replacements for three of the other key resources provided by windows—ventilation, lighting and view—have all proved significantly less acceptable to building occupants than their traditional equivalents, it was postulated that naturally-generated sensory variation was likely to be both clearly discernible from and consciously preferred to artificially-generated sensory change

Key Research Questions

1. Does it matter whether the movement of the digital-tree shadow is naturally or mathematically generated?

2. How do people rate the wind-animated digital-tree shadow against six other potential ways of compensating for a lack of windows?

3. Where do people feel the wind-animated digital-tree shadow would be most and least useful?

4. How do people value the ability to personally control the movement of the digital-tree shadow, versus the naturalness of the movement?

Experimental Objectives

1. The specific goals of the human subject experiments were to determine:

2. If people could tell the difference between natural, wind-generated visible movement, and similar, algorithmically-generated movement.

3. If naturally-generated movement was unconsciously preferred over artificially-generated movement.

4. If there was any conscious preference for naturally-generated movement.

5. If naturally-generated movement has any beneficial effect on heart rate, and how it compares to artificially generated movement.

6. How distracting people find naturally-moving digital images in a room.

7. How effective people think naturally-moving digital images would be compared to other ways of bringing nature and change into windowless spaces.

8. The relative importance of sensory change, live information about the surrounding environment, and connection to nature in indoor spaces.

9. Which kinds of spaces people feel naturally-moving digital images would be most and least appropriate in.

10. How people value the naturalness of visible movement against the ability to control it.

CHAPTER II

METHODOLOGY

Two principal methods were employed:

1. Objective comparison of the effects of natural and artificially generated movement of a digital-tree shadow on human heart-rate, using a finger-based heart-rate monitor.

2. Subjective comparisons of a naturally-animated digital tree-shadow with other potential methods of compensating for a lack of windows, using quantitative ratings of four key characteristics associated with traditional windows.

Establishing whether having naturally generated movement in a windowless space was significant, or if it could be just as effective to replicate such change artificially, was a key question. This was investigated in the test-room arrangement shown in Figure 1 through simultaneous heart-rate monitoring and a series of preference rating questions intended to compare occupants' responses to a digital-tree shadow moving according to natural changes in the wind or a mathematical algorithm (Figure 2).

It was important to establish whether knowing that such movement was either naturally or artificially generated affected how people evaluated it. Subjects were asked directly if knowing that movement was either natural or artificially generated would alter their opinion of it, and this was also tested objectively by asking them to evaluate movement patterns without knowing whether the movement was naturally or artificially generated, then showing them the same patterns falsely labeled to suggest that the naturally-generated movement was artificial and vice versa.

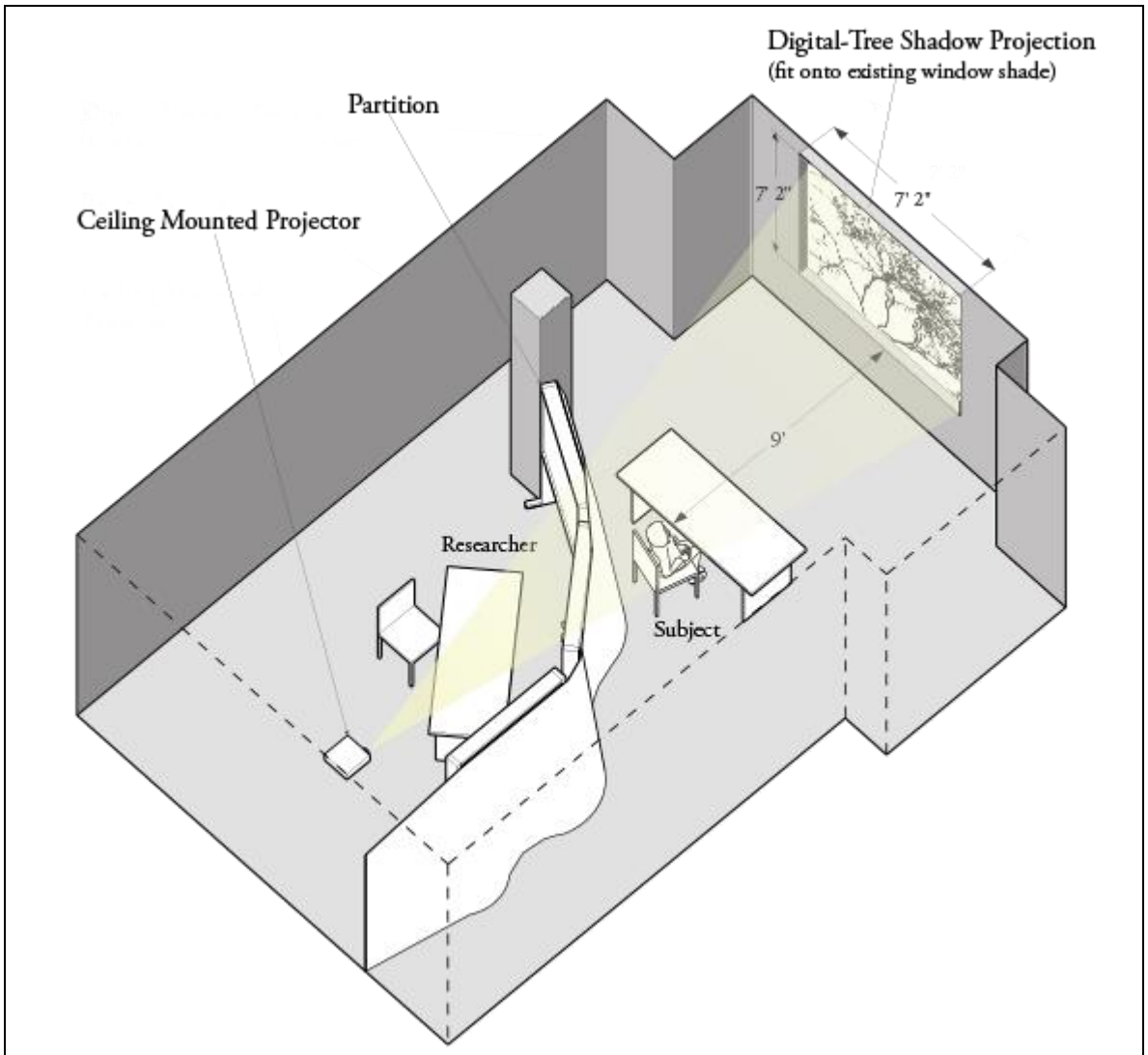

FIGURE 1. Test Room Arrangement

FIGURE 2. Still Image of the Animated Digital-Tree Shadow.

Following their exposure to the naturally and artificially moving digital-tree shadow, subjects were asked to quantitatively rate the natural wind-animated digital-tree shadow according to four key criteria (based on Heerwagen's analysis of the role of windows) in comparison to six other potential ways of bringing nature and change into windowless spaces (including an artificially-animated digital-tree shadow). They were also asked to quantitatively rate the appropriateness of using the naturally-animated digital-tree shadow in a range of indoor spaces.

In order to determine whether any particular kinds of movement were generally preferred, subjects were then encouraged to adjust the movement of a digital-tree shadow

according to their personal choice. Finally, they were asked to subjectively rank different combinations of natural and artificial movement and occupant control.

The natural movement was generated using wind-speed and direction sensors placed outside. The shadow animation was created using a combination of Arduino microcontrollers and the computer program 'Processing.' Data was collected via a micro-controller connected to the wind sensors, and was then relayed to a computer, where it was processed to generate the movement of a projected digital image. The same program was then used to artificially simulate natural wind movement patterns, which allowed mathematically generated and natural movement to be directly compared. For purposes of experimental consistency between subjects, both the naturally and algorithmically generated movement sequences were recorded beforehand.

Experimental Procedure

Upon arrival at a prearranged time, subjects were asked to sit at a table in the center of the test room. They were then given a copy of the University Participation Agreement as well as the experiment questionnaire. The researcher then provided background information regarding the basis of the experiment. Subjects were told that they were going to be asked to wear a finger-tip heart-rate monitor and to give their subjective assessments of videos of four different pre-recorded digital-tree shadow patterns according to a range of criteria, and would then be asked to adjust the shadow and its movement according to their personal preferences.

The subjects were then asked to sit and relax for two minutes in order to establish a baseline heart rate. After this was recorded, the video sequences began automatically. The shadow videos were separated by a slide with instructions to complete the relevant page of the survey. The heart-rate monitoring software was paused during the survey since the time taken to complete each page varied with different subjects. Subjects were shown the natural and artificially generated movement patterns in alternating sequence to cancel out any learning effect, with no indication of which was which, and were asked to assess each according to four key criteria associated with real windows (Figure 3).

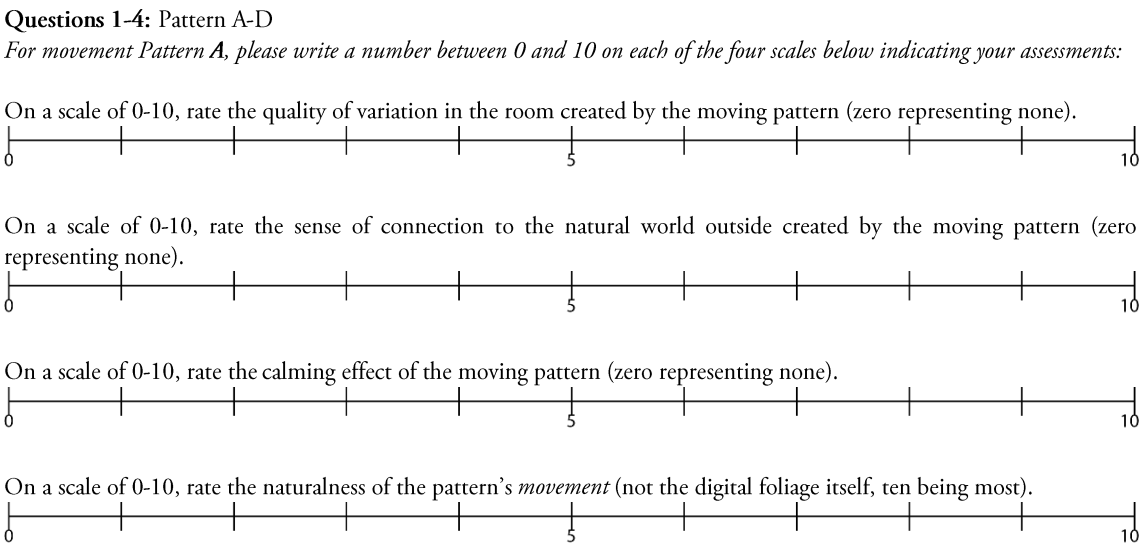

FIGURE 3. Question 1. This was answered for four patterns.

In preparation for the next test, the initial and final ten seconds were trimmed from the first two patterns so they were not recognizably the same. Subjects were then shown the trimmed patterns but were falsely informed that they were different patterns, and that the naturally generated movement was artificial and vice versa. This was intended to test objectively the effect that thinking movement was either natural or artificial might have on

how they were assessed. Subjects were also directly asked to estimate the likely effect of knowing that a pattern of movement was either natural or artificially generated would have on their assessment of it (Figure 4).

Would *knowing* the movement of an indoor pattern like this was *naturally generated* make it seem any *more satisfactory* to you?

Please circle one of the following answers:

A. Yes, significantly more satisfying B. Yes, slightly more satisfying C. No, it would make no difference.

Would *knowing* the movement of an indoor pattern like this was *computer generated* make it seem any *less satisfactory* to you?

Please circle one of the following answers:

A. Yes, significantly less satisfying B. Yes, slightly less satisfying C. No, it would make no difference.

FIGURE 4. Questions 5 & 6. Subjects' Self-Assessments of the Likely Effect of Knowing Movement Is Naturally or Artificially Generated

Subjects were then asked to rate the appropriateness of using the naturally moving digital shadow in different indoor spaces (Figure 5).

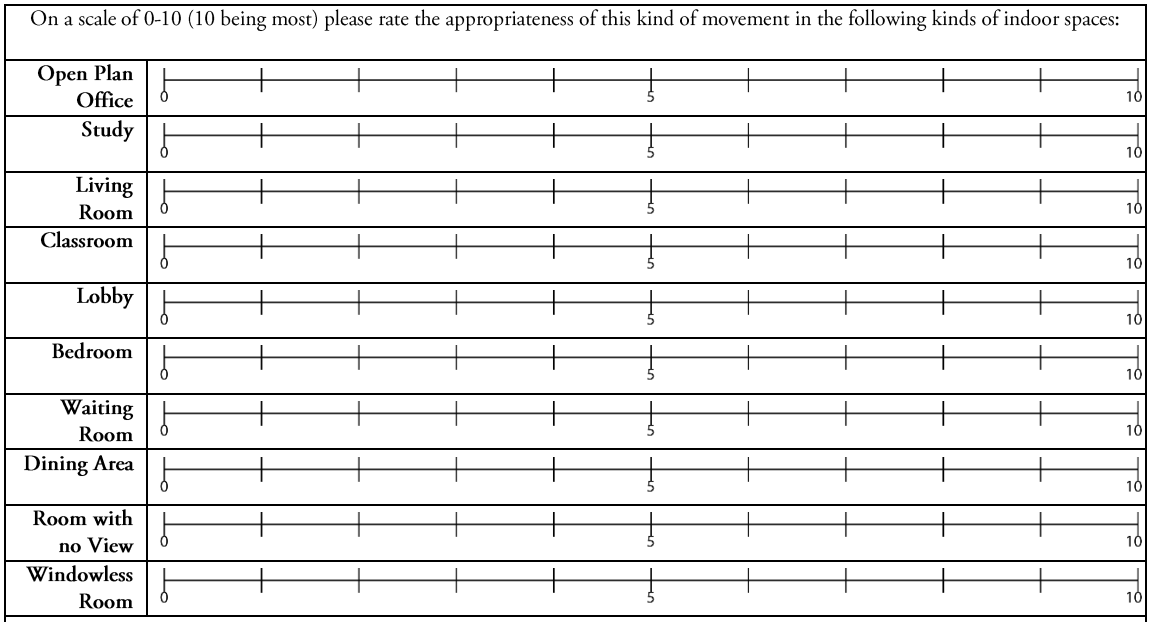

FIGURE 5. Question 7. Appropriateness of Different Room Locations for the Digital-Tree Shadow

Subjects were then asked to rate the likely effectiveness of the naturally moving digital tree shadow compared to six alternative ways of bringing nature and/or change into windowless spaces, according to four key criteria associated with windows (Figure 6).

On a scale of 0-10 (10 being the most effective), please rate the effectiveness of alternative ways of bringing nature and change into a windowless room (listed along the top row of the table below), according to the criteria listed in the left column.

Please write a number between 0 and 10 in each empty box in the matrix representing your estimate of the likely effectiveness of each potential method according to each criteria:

Windowless Room With: / Sense Of:	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
Connection to the Outside								
Connection to Nature								
Change in the Space								
Calming Effect								

FIGURE 6. Question 8. Likely Effectiveness of the Wind-Animated Digital-Tree Shadow in Comparison to Other Potential Means of Introducing Nature and Change into Windowless Spaces

Finally, subjects were asked to cycle through a series of computer-generated digital tree shadows until they found one that was pleasing to them, after which they were encouraged to adjust how it reacted to the wind, as well as the strength and direction of the wind force itself. To do this, they used five physical dials controlling wind direction, wind speed, wind-gust frequency, branch stiffness, and leaf stiffness. Each parameter affected the others, and subjects were allowed to keep readjusting each until they found a combination they found satisfying. They were then asked to note the values of the parameters they had chosen. Subjects' heart rates were monitored while they adjusted the artificial tree pattern to

their preferred configuration, and the process was also documented using a video screenshot recording.[22]

Subjects were then asked to fill in one final chart seeking their relative preferences for naturally-generated movement, adjustable natural movement, and artificially generated movement, and for their open-ended comments on the moving patterns, and in particular whether they would find them distracting. On completion of this last questionnaire, subjects were allowed to ask questions and finally were paid for their time in accordance with the University-approved agreement.[23]

Limits of the Study

Because of the additional testing time it would have required, the study did not attempt to directly measure the effect of the moving digital-tree shadow on performance. Subjects were instead asked to give their assessments of its likely distraction.

The study was limited to testing the effects of wind-generated movement, which is generally the most available of the potential sources of natural atmospheric change, and also varies the most rapidly. Electronic sensors exist for many other natural atmospheric changes, including temperature, air pressure and humidity; and these could be similarly used[24].

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[22] Since the trees were recursively drawn by the program, the same one was never created twice, however, subjects were allowed to refresh the generated tree until they found one they liked, within the parameters set by the researcher (leaf shape, number of branch, angle of branches, amount of leaves, etc…).

[23] See Appendix A for a copy of the approved university agreement

[24] These sources of natural environmental change could be explored in future studies, as could field-testing of effects on performance in different real-world room contexts.

Anticipated Outcomes

1. Subjects would be able to tell which of the movements of the digital tree shadow was naturally generated and which was artificially generated, and would find the naturally-generated movement more satisfying and less distracting.

2. Believing that movement was either natural or artificially generated would significantly affect subject's assessments of them.

3. People would value naturalness of movement more than the ability to control it.

CHAPTER III

RESULTS

Blind Assessments of Natural and Artificially Generated Movement

When unaware of the source of the movement of the digital-tree shadow, subjects generally could not distinguish between wind-generated and algorithmically-generated movement. There were also no significant differences in subjects' assessments of natural and artificially generated movement of the pattern in any of four key characteristics associated with windows: amount of change in the room, sense of connection to the outside, calming effect, and naturalness of movement (Figure 7).

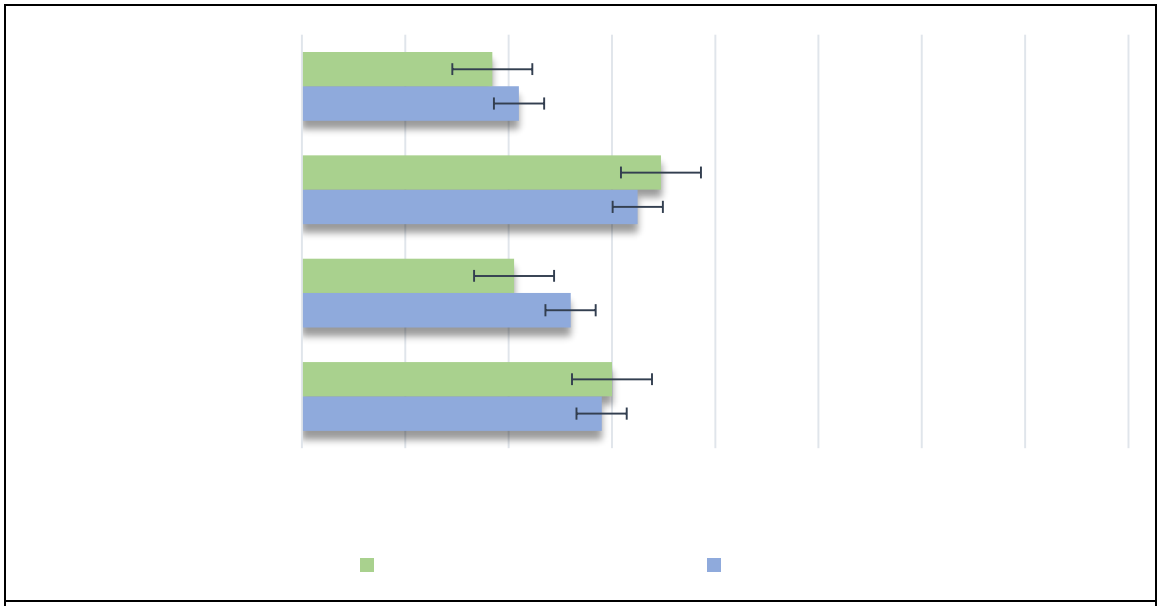

FIGURE 7. Subjects' Initial Unbiased Responses to Naturally and Artificially Generated Movement of the Digital-Tree Shadow

It had been expected that subjects would be able to detect a clear difference between the natural and artificially generated movement in at least some of these categories, but the

algorithm seems to have replicated natural movement so well that it was to all intents indistinguishable from wind-generated movement. Subjects' almost identical assessments of the natural and artificially generated movement of the digital foliage shadow suggest that it would be possible to digitally simulate natural movement to the point that people were unaware that the movement was not naturally generated. In other words, at least within this admittedly limited context, there does not appear to have been any elusive quality to the natural movement that could not be effectively replicated artificially.

The Effects of Believing Movement Is Either Naturally or Artificially Generated

There was a significant rise in subjects' assessments of the naturalness, calming effect, sense of connection to outdoors, and level of indoor change of the artificially-generated movement pattern they had seen in the first test when they were led to believe it was a different, naturally-generated pattern of movement (Figure 8).[25]

There was smaller, but still significant decrease in the perceived naturalness, calming effect, sense of connection to the outdoors, and level of indoor change of the naturally-generated movement pattern subjects had seen in the first test when they were led to believe it was a different, artificially-generated pattern (Figure 9).[26]

[25] When falsely believed to be natural, there was an 11% increase in perceived change in the space and a 22% increase in the sense of connection to outdoors. The perceived calming effect increased 12% and there was a 23% increase in the perceived naturalness of the movement (see Appendix B).

[26] Perceived change in the space decreased by 4%. The sense of connection to the outside world also decreased by 4%. When believed to be artificially generated. The calming effect was more drastically affected, decreasing by 13%, and there was a 16% decrease in the perceived naturalness of the movement. (See Appendix B).

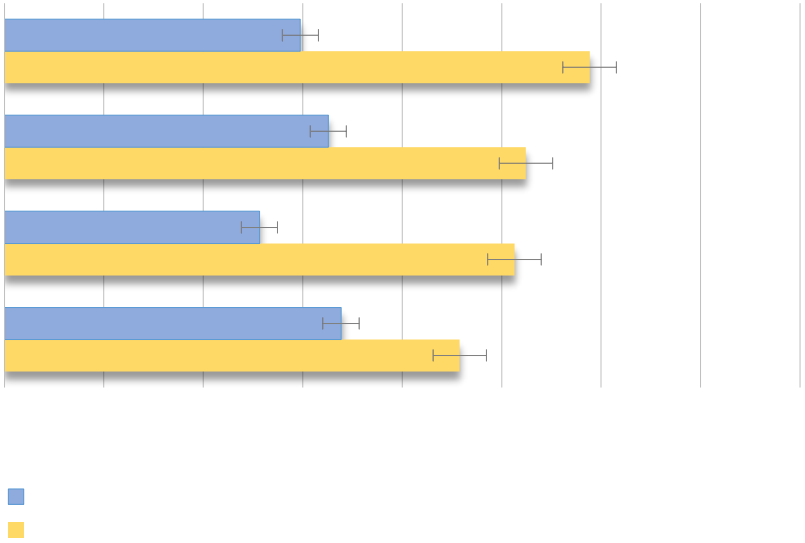

FIGURE 8. Effects on Subjects' Assessments of Artificially-Generated Movement When They Were Falsely Led to Believe It Was Naturally Generated.

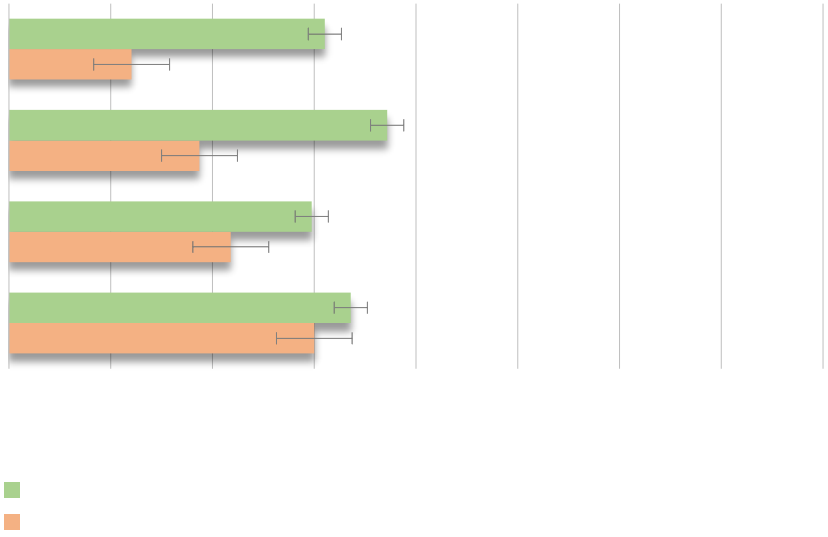

FIGURE 9. Effects on Subjects' Assessments of Naturally-Generated Movement When They Were Falsely Led to Believe It Was Artificially Generated.

Relative changes in subjects' assessments when they were falsely led to believe the movement of the digital-tree shadow was natural are shown in Figure 10.

	SENSORY CHANGE IN ROOM	CONNECTION TO OUTDOORS	CALMING EFFECT	NATURALNESS OF THE MOVEMENT
FALSELY BELIEVED NATURAL	+10%	+24%	+18%	+27%
FALSELY BELIEVED ARTIFICIAL	-3%	-7%	-15%	-17%

FIGURE 10. Percentage Changes in Subjects' Assessments of Movement When Falsely Led to Believe It Was Either Naturally or Artificially Generated

The belief that a pattern of movement was naturally generated significantly improved subjects' assessments of it; while the belief that movement was artificially generated had a lesser, but still significant opposite effect. While it may be technically possible to fool people into thinking that mathematically generated movement is natural, then, there would seem to be only two ethical options for using the digital tree shadows:

1. Openly using naturally generated wind movement to take advantage of its significant positive associations

2. Openly using artificially generated movement and accepting a significant fall off in occupants' assessments of its value

Subjects' Self-Estimates of the Effects of Knowing that Movement Is Naturally or Artificially Generated

A majority of subjects believed that knowing movement was naturally generated would have only a slight or no effect on their assessment of it (51% and 18% respectively) (Figure 11).

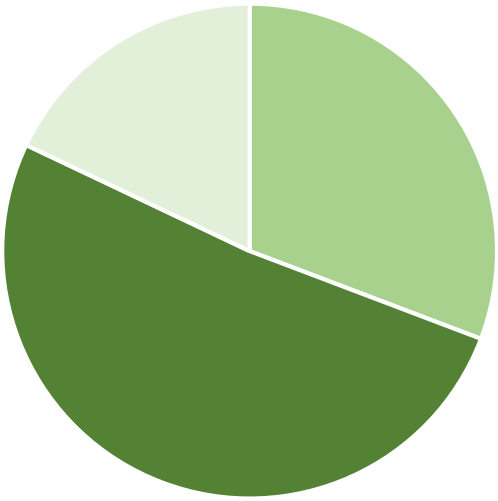

FIGURE 11. Subjects' Self-Assessments of the Likely Effect of Knowing That Movement Is Naturally Generated

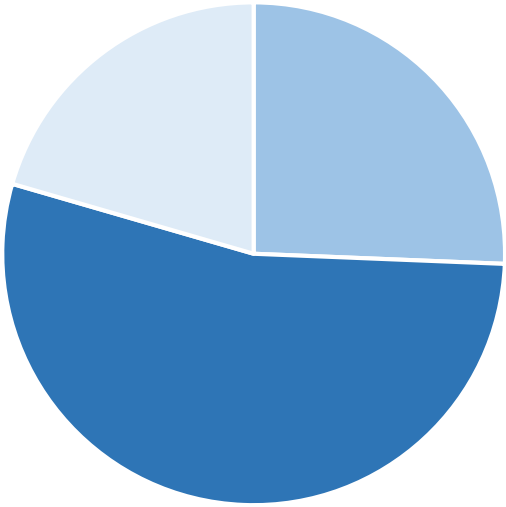

FIGURE 12. Subjects' Self-Assessments of the Likely Effect of Knowing That Movement Is Artificially Generated`

A similar majority of subjects believed that knowing movement was artificially generated would have only a slight or no effect on their assessment of it (54% and 20% respectively) (Figure 12).

Most subjects thought that knowing movement was either naturally or artificially generated would have little or no effect on their assessment of it. The objective results of the previous test, however, indicate that they greatly underestimated the effect of this knowledge.

Subjective Estimates of the Likely Effectiveness of Different Means of Bringing Nature and/or Change into Windowless Spaces

In terms of both its likely calming effect and sense of change in the space,[27] the naturally-animated digital foliage shadow was judged likely to be the most effective method of bringing nature and change into windowless spaces.[28] Only live footage of a remote natural scene or a natural scene immediately outside was preferred to the wind-animated digital shadow in terms of connection to nature and the world outside (Figures 13-16).[29]

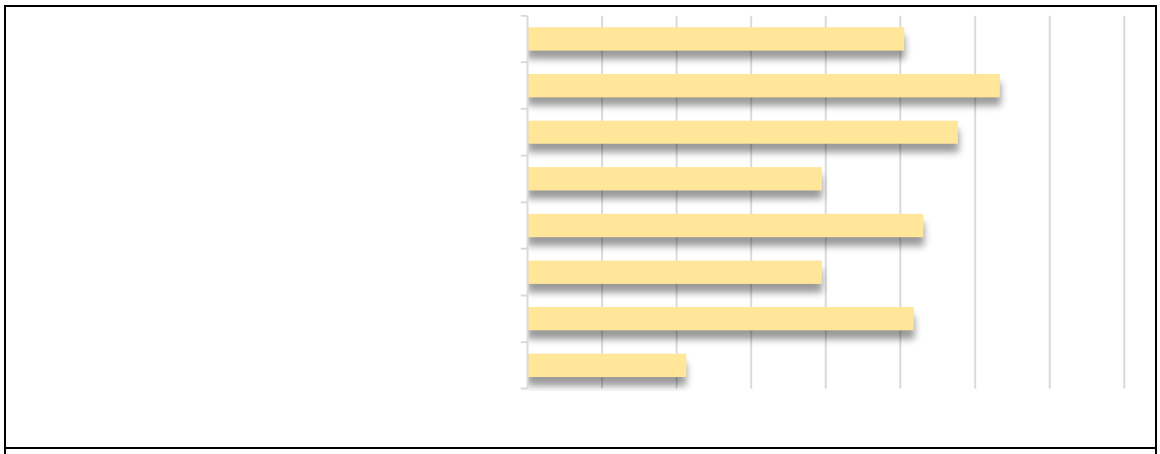

FIGURE 13. Subjects' Estimates of the Likely Calming Effect of Different Means of Bringing Nature or Change into Windowless Spaces

[27] Receiving 11% more points than the next highest rated method.

[28] By an average of 5% more points than the next potential means.

[29] By a margin of 3% naturally animated digital foliage was considered the second most effective method (after a live webcam of a remote natural scene). The naturally animated digital foliage was considered the third most effective; after a live webcam of a remote natural scene and live security camera footage of a natural scene immediately outside.

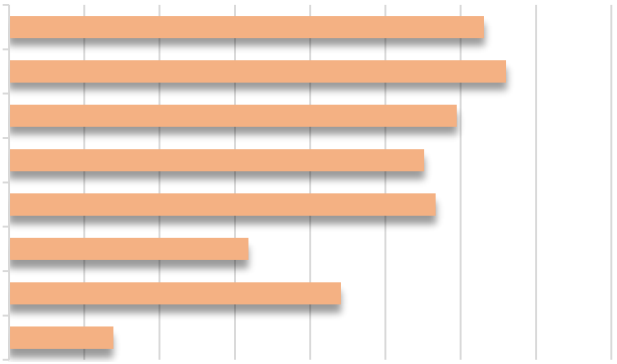

FIGURE 14. Subjects' Estimates of the Likely Amount of Perceptible Change Introduced Through Different Means of Bringing Nature or Change into Windowless Spaces

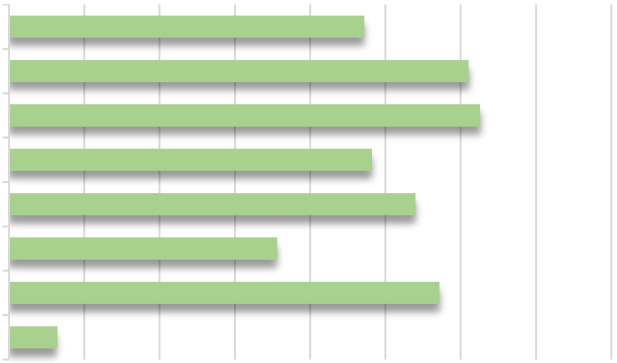

FIGURE 15. Subjects' Estimates of the Likely Sense of Connection to Nature Created by Different Means of Bringing Nature or Change into Windowless Spaces

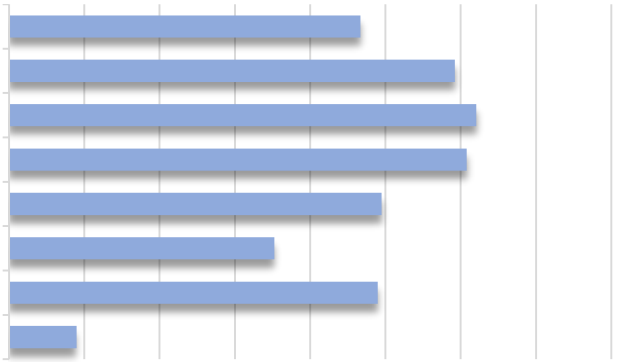

FIGURE 16. Subjects' Estimates of the Likely Sense of Connection to the Outside Created by Different Means of Bringing Nature or Change into Windowless Spaces

Generally speaking, live, natural information seemed most important to subjects. However, the localness of the source of that information did not appear to be critical. The only methods that were preferred to the naturally-animated digital-tree shadow in any category had the same two essential characteristics—liveness and connection to nature—but provided more visual information. The one slight surprise was that in two categories subjects preferred a full remote scene to the partial local information provided by the digital-tree shadow. Overall, the wind-animated digital-tree shadow was rated the highest, finishing at or towards the top in all of the tested categories (Figure 17).

Windowless Room With: / Sense Of:	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
Connection to the Outside	0.90	4.90	3.53	4.95	6.08	6.21	5.92	4.67
Connection to Nature	0.64	5.72	3.56	5.40	4.82	6.26	6.10	4.72
Change in the Space	1.38	4.41	3.18	5.67	5.51	5.95	6.60	6.31
Calming Effect	2.13	5.18	3.95	5.31	3.95	5.77	6.33	5.05
Total Rating	5.05	20.21	14.22	21.32	20.36	24.18	24.96	20.74
Color Key	First	Second	Third					

FIGURE 17. Subjects' Estimates of Likely Effectiveness of the Wind-Animated Digital-Tree Shadow in Comparison to Other Potential Means of Introducing Nature and Change into Windowless Spaces

Subjects' Views on the Most Appropriate Room Locations for Animated Digital-Tree Shadows

A significant majority of subjects (63%) felt that the most appropriate room location for the moving digital foliage would be in windowless spaces or rooms without views. Most felt it would be least appropriate in a classroom (53%), or a dining space (40%) (Figure 18).

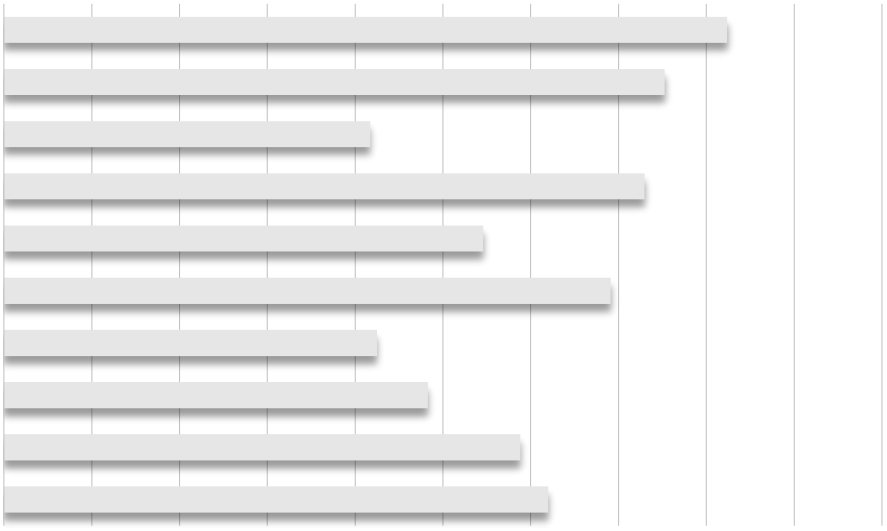

FIGURE 18. Subject Ratings of the Appropriateness of the Animated Digital-Tree Shadow in Different Room Types

The clear preference for use of the digital foliage shadow in windowless spaces was as expected. It seems safe to assume that most subjects were against its use in classrooms because of concerns about distraction (ironically, a reason often given to justify windowless classrooms).[30] This, presumably, was also the reason for many subjects being against its use

[30] Belinda L. Collins, Windows *and People: A Literature Survey. Psychological Reaction to Environments with and Without Windows*. No. NBS-BSS-70. National Bureau of Standards, Washington, DC (USA); US Dept. of Commerce, National Bureau of Standards, Institute for Applied Technology, Washington, DC 20234, 1975.

in a dining area. The latter came as a surprise, given that many people today routinely multi-task while eating.

Potential Distraction

Distraction was not directly measured through performance testing, but in a free response section at the end of the survey subjects were asked whether or not they found the moving patterns distracting. 32% answered that they did not find it all distracting; another 43% said it was not distracting in the tested situation, but that it might be in a different context or at higher wind speeds. The remaining 25% of subjects who responded said it was at least a little distracting: 5% said it was a little distracting, 8% said it was distracting, and 8% said it was distracting in a good way. 5% did not respond to this question (Figure 19).

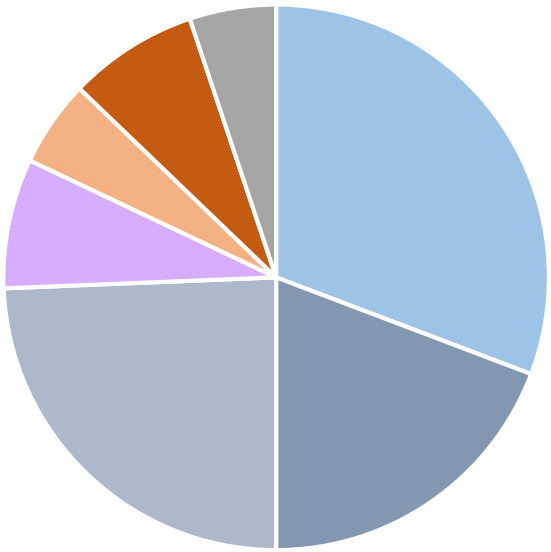

FIGURE 19. Subjects' Estimates of the Likely Distraction Caused by the Moving Digital-tree Shadow

The fact that a majority of subjects did not find the shadow distracting suggests that the digital tree shadows could be of value even in some working environments.

Control vs. Naturalness of Movement

Of four alternative permutations of naturally or artificially-generated movement with or without user control, a significant majority of subjects preferred naturally-generated movement that they could be adjusted by the user (Figure 20). This suggests that while most people like the *idea* of wild nature, they prefer to be able to control it in their own environment. Indeed, when asked to choose between naturalness and control, controllability slightly outweighed naturalness.[31]

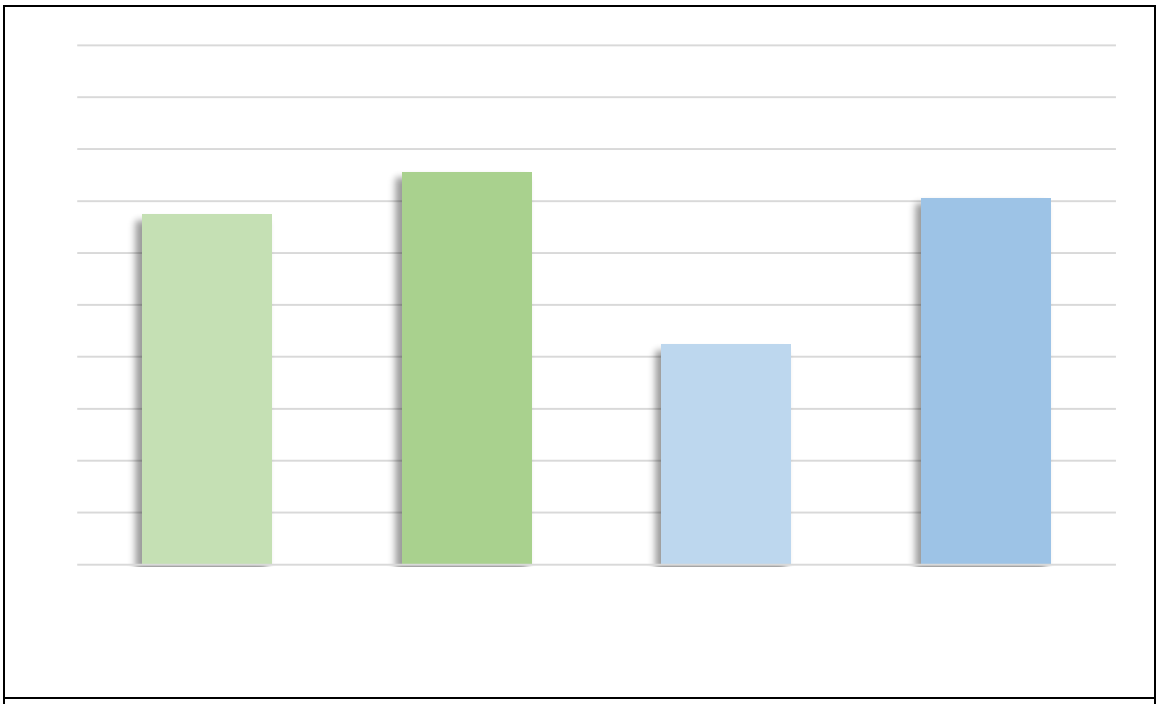

FIGURE 20. Subjects' Preferences for Naturalness Versus Controllability of Movement

[31] The controllable shadow had an average preference rating 6% higher than the uncontrolled, naturally-generated digital shadow.

Subject-Adjusted Tree Movement

When subjects were given an opportunity to choose from different artificially generated tree shadows, most chose a relatively symmetrical tree form with branches full of leaves. Subjects were then asked to adjust how the tree interacted with the wind.[32] Two thirds of subjects preferred a tree that swayed easily in response to a light breeze,[33] and more than 80% of the subjects chose to have the leaves follow the sway of the branches.[34]

Subjects were also able to adjust the wind speed and direction. Three quarters chose a wind setting that that blew from side to side,[35] and a significant majority (85%) chose it to occur at a low wind speed.[36] The preferred frequency of wind gusts varied more widely, but 44%[37] chose to have frequent, short gusts.[38]

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[32] When choosing dial settings, subjects were given a range from 0-10 for all settings except for direction which was between 0 and 360. Results were totaled and separated into three categories for analysis.

[33] Of the remaining subjects, 26% chose a tree that swayed very little, and the remainder (7%) chose a branch resistance that only allowed the leaves to move.

[34] 51% chose to have the leaves blow uniformly, 31% of subjects chose to have most movement in the same direction and at the other extreme, 18% chose to have the leaves move independently of the wind direction

[35] 49% chose wind moving from left to right, 26% chose to have the wind blowing from right to left.

[36] The speed setting provided values similar to those received from the anemometer for the live movement. A low wind speed was 1-5 mph, a medium wind speed would be 10-15mph, and a high wind speed is >20mph. While 10% chose a medium wind speed, only a few subjects (5%) enjoyed high winds speed

[37] The rest were split between intermittent (26%) and long (30%) gusts of wind.

[38] Exact frequencies varied based on the other chosen settings on average, a short was <1 second apart, an intermittent gust was 1-3 seconds, and a long gust was >5 seconds or constantly blowing.

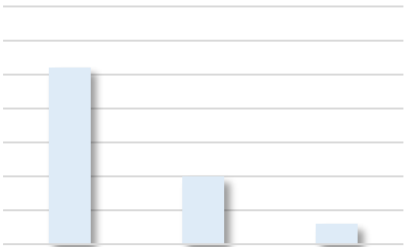

FIGURE 21. Subjects' Branch-Stiffness Preferences

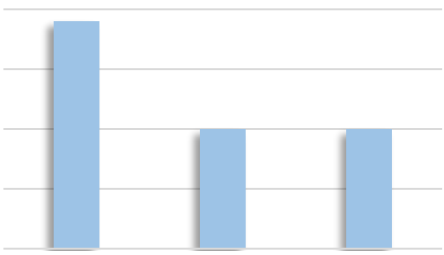

FIGURE 22. Subjects' Wind-Direction Preferences

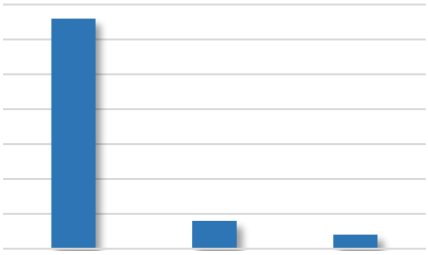

FIGURE 23. Subjects' Wind-Speed Preferences

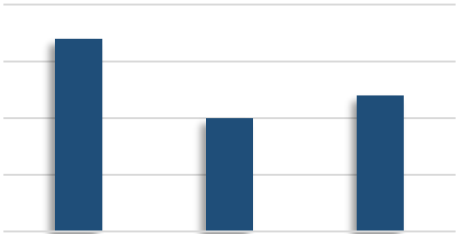

FIGURE 24. Subjects' Wind-Gust Frequency Preferences

A typical 'ideal' based on the compiled preferences seemed to be a slow rhythmically moving tree. This was unlike the small, sudden movements of the naturally moving tree shadow, and similar to the parameters used for the artificially-generated movement in the first part of the study.

One of the most surprising findings from this part of the study was the marked calming effect on subject heart rates of being able to adjust the movement. On average, this matched or exceeded that of both the natural and artificially movement on their own, and was consistent with subjects' expressed preference for the ability to control the movement.

Effects on Heart Rate

When subjects were unaware of the source of the movement, both naturally and artificially generated movement had a clear calming effect on their heart rates in comparison to their average base heart rates recorded when they were sitting inactively without any visible movement in the room. Average base heart rates in the static room increased noticeably over time, probably due to boredom, a frequent cause of stress in everyday life.[39] However, this boredom-induced stress seems to have been effectively staved off by the presence of the moving shadow pattern, and surprisingly, slightly more by the artificially-generated movement than the naturally-generated movement (Figure 25).

Believing that movement was either natural or artificially generated did not appear to cause any noticeable physiological change in subjects' heart rates. This was in contrast to the psychological effect, which was significant.

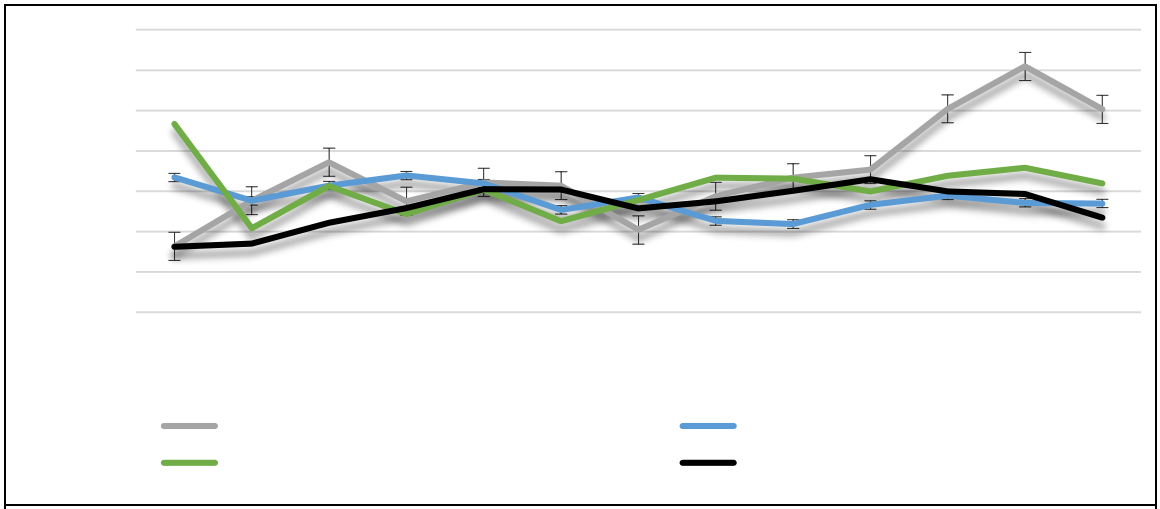

FIGURE 25. Subject Heart Rates with Different Sources of Shadow Movement

[39] See Leo. Goldberger, "Sensory Deprivation and Overload." In *Handbook of Stress: Theoretical and Clinical Aspects*, ed. Leo Goldberger and Shlomo Breznitz, 333-335. Simon and Schuster, 1993.

CHAPTER IV

INTERPRETATION

There could be a number of potential explanations for why subjects generally could not visually distinguish between natural, wind-generated movement and similar, algorithmically-generated movement. It may be that there is no special quality in natural movement that cannot be effectively replicated artificially, or alternatively, the medium itself may have limited the expression of the natural movement so much that it became indistinguishable from that generated by the algorithm.[40] Even when people could not distinguish between the two, however, knowing whether or not movement is naturally-generated had a significant effect on how it was assessed.

Technically it is seemingly possible to make artificially-generated movement indistinguishable from naturally-generated movement, however, the distinction is important to most people.[41] As a result, there would seem to be two compelling reasons to use naturally generated movement:

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[40] The particular age group of most of the subjects (between 18 and 24 years) may have amplified this effect. Peter Kahn and others have suggested that as generations spend less time in contact with nature, their ability to distinguish between artificial simulations and the real thing will decrease. *See* Peter H. Kahn, "Environmental Generational Amnesia" In *Technological Nature: Adaptation and The Future of Human Life*, 163-183. MIT Press, 2011. It might be worth adding that I myself fall into this category. I learned to type before I could write, and 'punishments' often included having electronic gadgets removed and being told to 'go outside.'

[41] "To some, there is no surrogate for nature… Roger Ulrich and Rachel and Stephen Kaplan have documented the preference for nature, at least in contemporary Western culture…When Martin Krieger judiciously asked, 'What's Wrong With Plastic Trees?' Iltis labeled him as someone who might get his sexual satisfaction from plastic mannequins." From Robert B. Riley *Attachment to the Ordinary Landscape* in *Place Attachment*, eds. Irwin Altman and Setha M. Low, 13-35. Plenum Press, 1992. See also Martin H. Krieger, "What's Wrong with Plastic Trees?: Rationales for preserving rare natural environments involve economic, societal, and political

1. People strongly prefer knowing that movement is naturally generated, even when they cannot directly tell that it is.

2. It would be unethical to misrepresent artificial movement as natural.[42]

The fact that the moving patterns generally seemed to have a calming effect on subject heart rates, apparently acting to stave off the effects of stress due to boredom, is consistent with the findings of the pioneer of sensory deprivation research Donald Hebb.[43] It was a surprise to find that the artificially-generated movement seemed to have a greater calming effect than the naturally-generated movement, however, which appeared to contradict other studies.[44] One possible explanation is that, because of the additional processing involved, the algorithmically-generated movement appeared noticeably smoother than the wind-generated movement, something commented on by several subjects.

The fact that just under half the subjects felt that any potential distraction caused by the moving digital image would depend on the context and the speed of its movement, while roughly a third thought it would not be distracting at all, was consistent with the finding that most subjects felt this kind of movement would be most useful in windowless spaces, but least appropriate in classrooms.

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factors." *Science* 179, no. 4072 (1973): 446. And Hugh H. Iltis, "Can One Love a Plastic Tree?" *Bulletin of the Ecological Society of America* (1973): 5-19.

[42] See the discussion on plastic trees in Ernest Partridge, "Ecological morality and Nonmoral Sentiments." *Land, Value, Community: Callicott and Environmental Philosophy* (2002): 21.

[43] Donald O. Hebb, "Drives and the Conceptual Nervous System." *Psychological Review* 62, no. 4 (1955): 243.

[44] Nute, Kevin, *et al.* "The Animation of the Weather as a Means of Sustaining Building Occupants and the Natural Environment." *International Journal of Environmental Sustainability*, 1 (2012).

It was a surprise that when given a choice between entirely naturally generated movement and adjustable movement, most subjects valued control as much if not more than the naturalness of the movement. This would appear to contradict findings such as those of the Kaplans' in their 'nearby nature' garden study,[45] in which the subjects ranked natural fascination significantly higher than control in terms of satisfaction (2nd as opposed to 7th of 9 factors). However, this apparent desire to adjust nature, to make it bend to our requirements, is nothing new. The geographer Yi Fu Tuan, for example, describes the control of nature, initially in the form of the garden, as a fundamental trait of human development.[46] And Schneider and Morton suggest that humans often exhibit two opposing attitudes to nature; affinity and a wish to conserve it, and, fear, and a desire to control it.[47] It would appear, however, that this result may have been driven more by a wish to control one's environment than a desire to control nature *per se*. Monica Paciuk's study for the National Building Research Institute in Israel, for example, suggested "a link between the comfort responses of office employees and their perceived degree of control of environmental conditions at their workspaces."[48]

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[45] Rachel and Stephen Kaplan. *The Experience of Nature: A Psychological Perspective*. Cambridge University Press, 1989.

[46] "The garden is humanized order close to earth. The course toward civilization is marked by the rise of the garden at the expense of wilderness, and the rise of the city at the expense of the garden" Yi-Fu Tuan *Man and Nature*. Resource Paper 10, Commission on College Geography, Washington DC: Association of American Geographers, 1971, 24.

[47] See Stephen Henry Schneider and Lynne Morton, *The Primordial Bond: Exploring Connections Between Man and Nature Through the Humanities and Sciences*. Plenum Press, 1981.

[48] Even these findings come with a warning: "Control can be a mixed blessing when exercising it exacts costs Paraphrased by Monica Paciuk, "The Role of Personal Control of the Environment in Thermal Comfort and Satisfaction at the Workplace." PhD diss., University of Wisconsin-Milwaukee, 1989.

CHAPTER V

CONCLUSIONS

A wind-animated digital-tree shadow was tested as a potential retrofit for windowless spaces.[49] Physiologically, it did not appear to matter whether movement of the digital tree shadow was naturally or mathematically generated. Most subjects could not visually tell the difference, and both had a similar calming effect on heart-rates. Psychologically, however, knowing that the movement was naturally generated was important, significantly more so than subjects themselves had estimated.

Compared to six other potential ways of introducing nature and/or change into windowless spaces, including a mathematically-animated digital-tree shadow, the wind-animated digital-tree shadow was rated best overall, highest for calming effect and sensory change, and in the top three in terms of connection to nature and to the outdoors. It was only bettered in the latter two characteristics by live full video footage of local and remote outdoor scenes.

The majority of subjects felt that the wind-animated digital tree shadow would be of most potential value in windowless environments, and least appropriate in spaces where it might negatively distract, such as classrooms. And finally, user control of the movement was found to be as if not more important to subjects than the naturalness of the movement.

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[49] While it would seem of greatest potential value in windowless environments, the digital shadow could also be helpful in other indoor situations where occupants are commonly under-stimulated, including waiting areas, senior living or long-term nursing facilities for example.

It would seem that a wind-animated digital-tree shadow, or something similar, could be a cost-effective means of compensating for an absence of windows because it appears to successfully replicate two key characteristics of real windows, in providing naturally-varying sensory change and a sense of live connection with the outdoor world.

Although both virtual windows and live closed-circuit television footage can provide greater visual information about the world outside, unlike a real window, for example, they are focused almost entirely on external views, and other than sound, tend to bring relatively little perceptible change into a room beyond the limits of their frame. The greater sensory variation introduced into a space by the digital-tree shadow, on the other hand, combined with its reduced visual information, would seem to have the potential to maintain occupants' alertness without being as consciously distracting as full electronic views.

The environmental psychologist Judith Heerwagen has suggested that windows provide four key benefits to building occupants: environmental information, sensory change, connection to the world outside, and restoration.[50] The results of the current study suggest that the following strategies could be most effective in compensating for an absence of windows:

1. Establishing a *live* connection with the outdoors (though not necessarily with the environment immediately outside)
2. Introducing *controllable* sensory variation into a space
3. Making such change *a source of natural environmental information*, and being certain occupants know this.

[50] Heerwagen, "The Psychological Aspects of Windows and Window Design," 273.

These approaches could be helpful either separately or in combinations, but a live connection with the outdoors that introduces controllable naturally-generated change into a space would seem likely to be most effective.

APPENDIX A

HUMAN SUBJECT TESTING MATERIALS

Participation Agreement

You are invited to participate in a research study conducted by Graduate Student Jeffrey Stattler and Professor Kevin Nute, from the University of Oregon Department of Architecture. As part of a Master's thesis focusing on improving the habitability of windowless environments, we hope to establish whether or not occupants of windowless rooms can distinguish a source of movement based on projected shadows in a space. You were selected as a possible participant in this study because of your availability during summer term and for your unique understanding of the built spaces you inhabit.

If you decide to participate, you will be asked to sit inactively in a windowless room wearing a heart rate monitor clipped to your finger. During this time two different moving patterns will be projected on a wall nearby. After each pattern, you will be asked to complete a short questionnaire. This process will then be repeated with two different patterns. This process will help us to determine which type of movement is most preferred both consciously (via the questionnaire) and unconsciously (via the heart rate monitor).

You will be in a small windowless room for up to an hour. If you feel uncomfortable for any reason, you may take a break or withdraw from the study at any time. By participating in this experiment you will hopefully gain greater awareness of the importance of change in indoor environments. However, I cannot guarantee that you personally will receive any benefits from this research. Upon completion of your part of the experiment, you will be paid $10.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Subject identities will be kept confidential by assigning each participant a number with only a hard copy list connecting subject names and numbers. This list will be kept for record keeping purposes only under lock and key by the supervising professor. All questionnaires and data analyses will only use the anonymous subject numbers. If necessary, only participant sex and age will be identifying elements used to describe responses, reactions, participation levels, etc. (e.g. The twenty-four year old female liked the first pattern).

Your participation is voluntary. Your decision whether or not to participate will not affect your relationship with The University of Oregon. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without penalty.

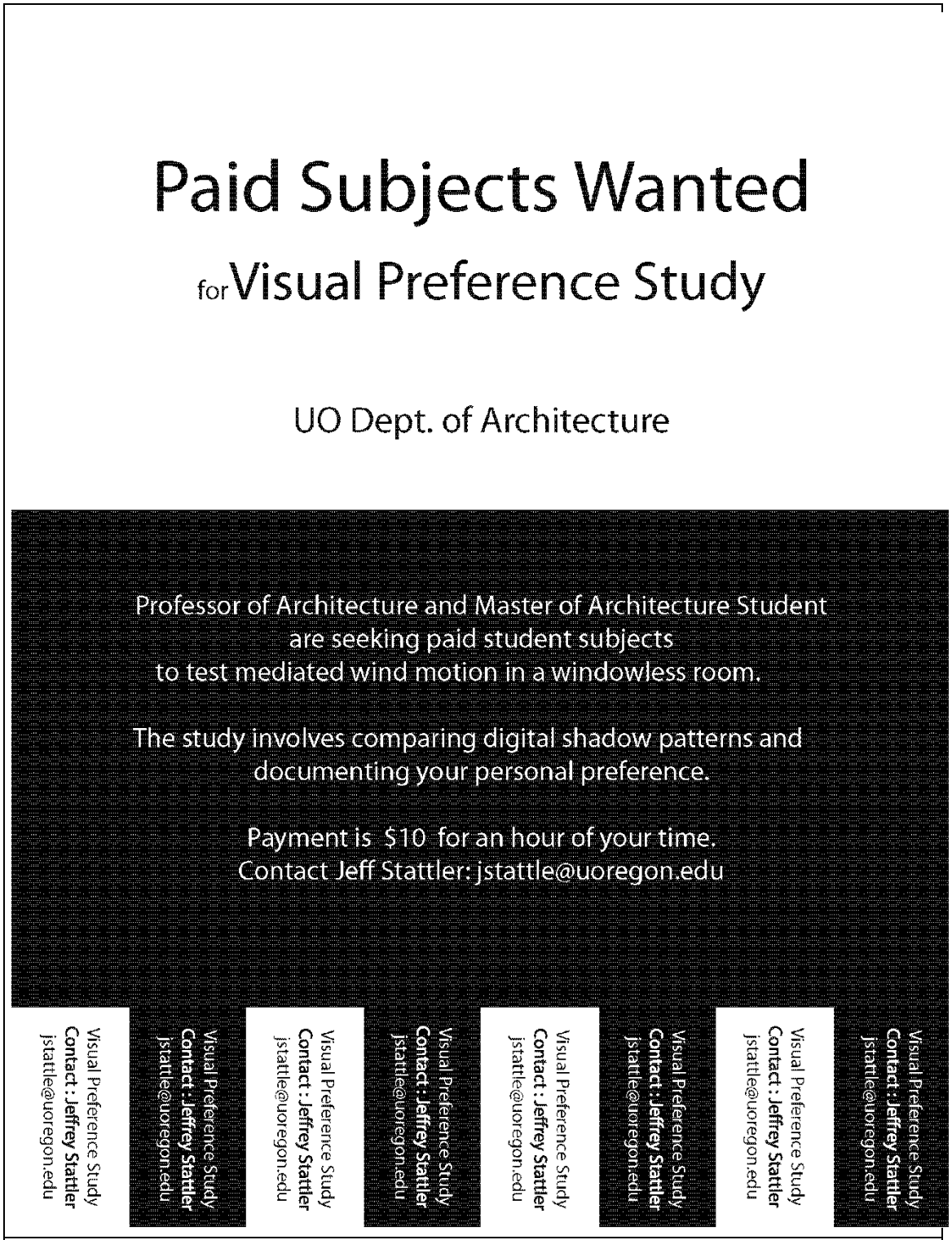
If you have any questions, please feel free to contact the researcher, Jeffrey Stattler, by phone: 626.825.3203 or email: jstattle@uoregon.edu or the advisor, Kevin Nute, at knute@uoregon.edu. If you have questions regarding your rights as a research subject, contact Research Compliance Services, University of Oregon, Eugene, OR 97403, (541) 346-2510. You have been given a copy of this form to keep.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, and that you are not waiving any legal claims, rights or remedies.

Print Name_____

Signature _____
Date_____

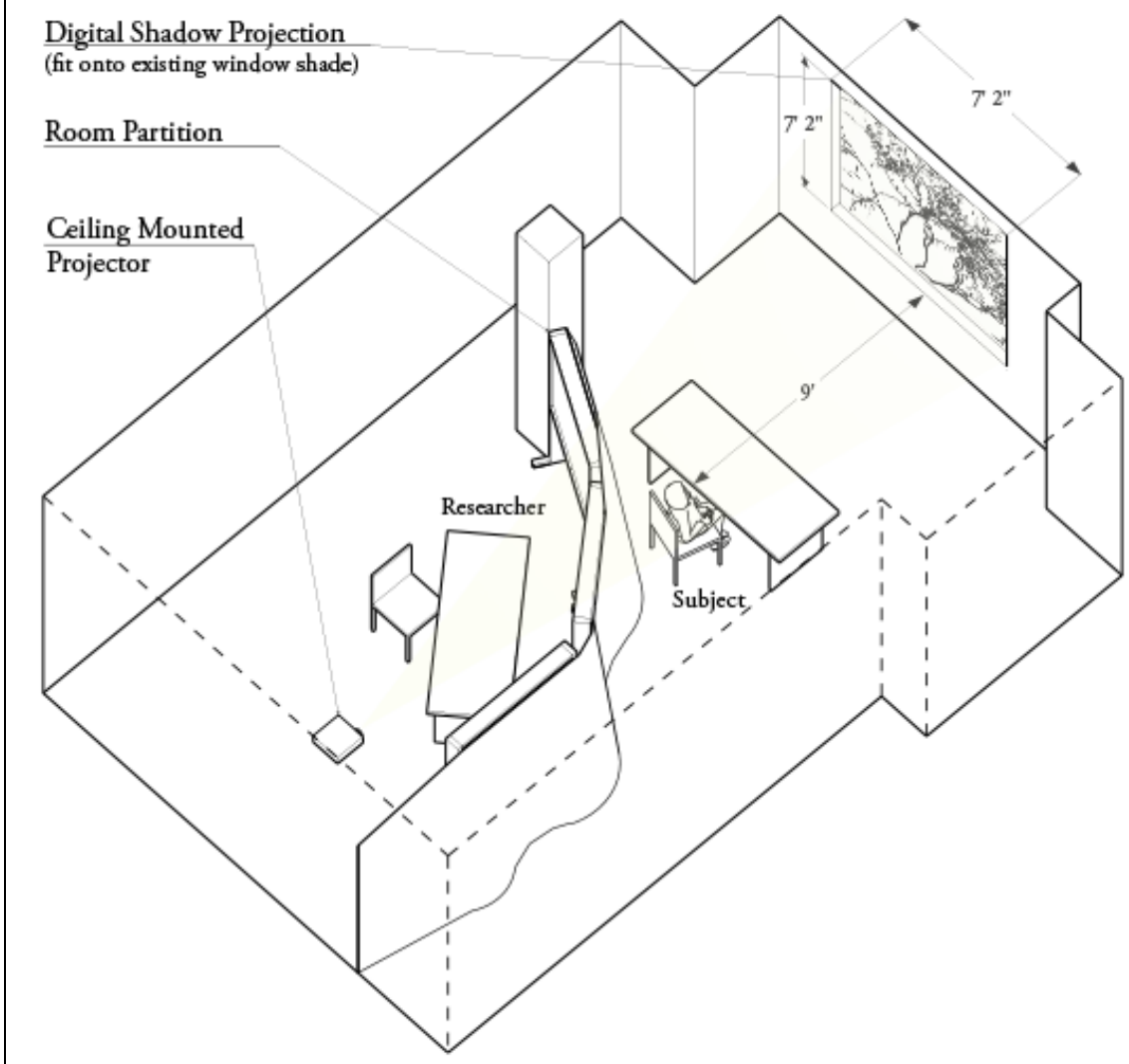
University Agreement for the Human Subjects Study



Recruitment Poster for the Human Subjects Study

Stills From Digital Shadow Videos. Both Artificially Generated one is labeled Falsely.

Stills From Digital Shadow Videos. Both Naturally Generated one is labeled Falsely.



Arrangement of the Test Room

Test Room Photos. From top to bottom: subjects side of the room , subjects seated view

Visual Preference Study

Name:

Date:

Age:

Area of Study:

Email:

Question 1: Pattern A

*For movement Pattern **A**, please write a number between 0 and 10 on each of the four scales below indicating your assessments:*

On a scale of 0-10, rate the quality of variation in the room created by the moving pattern (zero representing none).

On a scale of 0-10, rate the sense of connection to the natural world outside created by the moving pattern (zero representing none).

On a scale of 0-10, rate the calming effect of the moving pattern (zero representing none).

On a scale of 0-10, rate the naturalness of the pattern's *movement* (not the digital foliage itself, ten being most).

Question 2: Pattern B

*For movement Pattern **B**, please write a number between 0 and 10 on each of the four scales below indicating your assessments:*

On a scale of 0-10, rate the quality of variation in the room created by the moving pattern (zero representing none).

On a scale of 0-10, rate the sense of connection to the natural world outside created by the moving pattern (zero representing none).

On a scale of 0-10, rate the calming effect of the moving pattern (zero representing none).

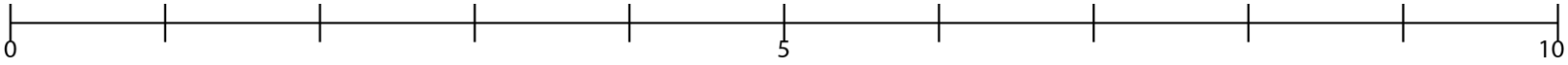
On a scale of 0-10, rate the naturalness of the pattern's *movement* (not the digital foliage itself, ten being most).

Question 3

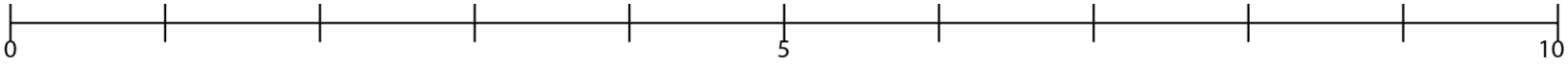
Please Note: the *movement* of pattern C was naturally generated by the wind

For movement Pattern C, please write a number between 0 and 10 on each of the four scales below indicating your assessments:

On a scale of 0-10, rate the quality of variation in the room created by the moving pattern (zero representing none).

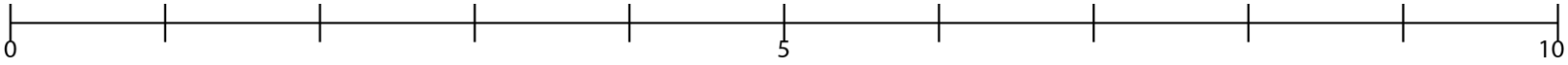


On a scale of 0-10, rate the sense of connection to the natural world outside created by the moving pattern (zero representing none).



On a scale of 0-10, rate the calming effect of the moving pattern (zero representing none).

On a scale of 0-10, rate the naturalness of the pattern's *movement* (not the digital foliage itself, ten being most).



Question 4

Please Note: the *movement* of pattern D was artificially generated by a computer

*For movement Pattern **D**, please write a number between 0 and 10 on each of the four scales below indicating your assessments:*

On a scale of 0-10, rate the quality of variation in the room created by the moving pattern (zero representing none).

On a scale of 0-10, rate the sense of connection to the natural world outside created by the moving pattern (zero representing none).

On a scale of 0-10, rate the calming effect of the moving pattern (zero representing none).

On a scale of 0-10, rate the naturalness of the pattern's *movement* (not the digital foliage itself, ten being most).

Question 5

Would *knowing* the movement of an indoor pattern like this was *naturally generated* make it seem any *more satisfactory* to you?

Please circle one of the following answers:

A. Yes, significantly more satisfying B. Yes, slightly more satisfying C. No, it would make no difference.

Question 6

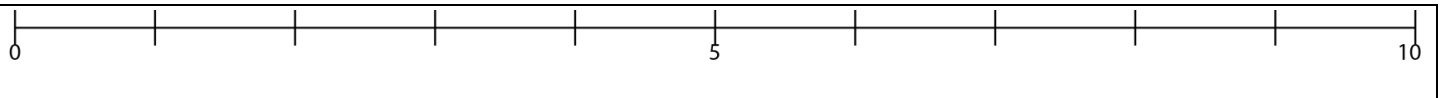
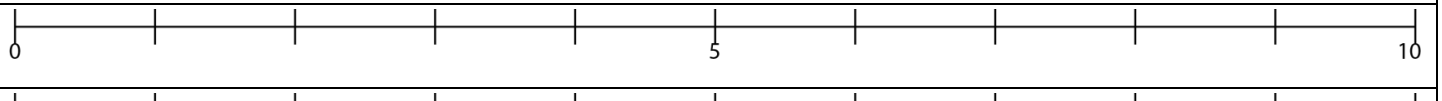
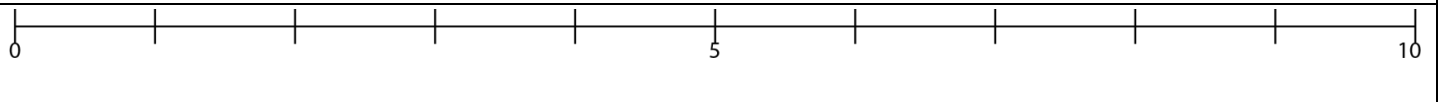
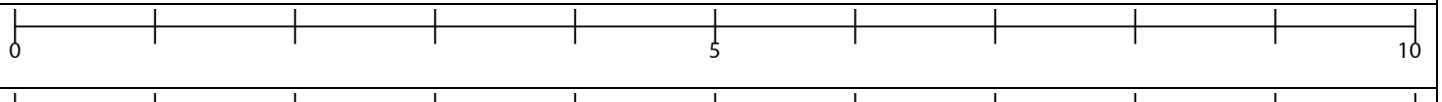
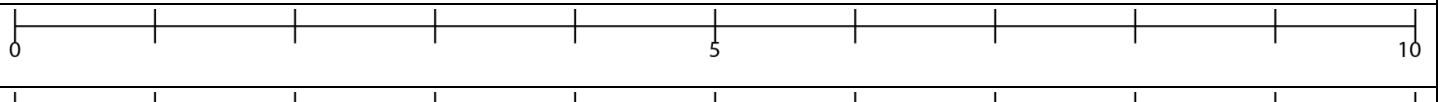
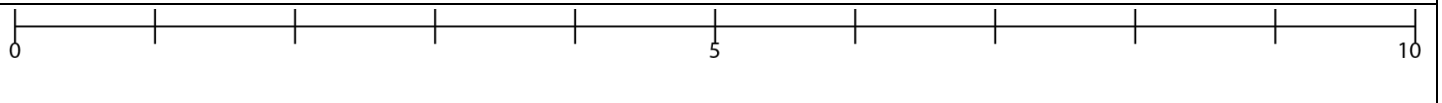
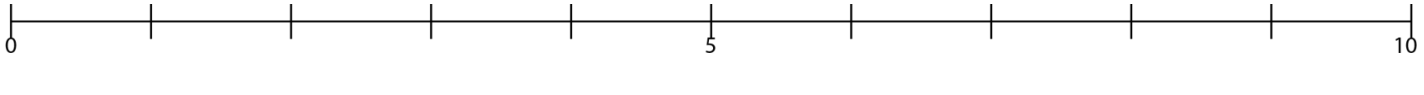
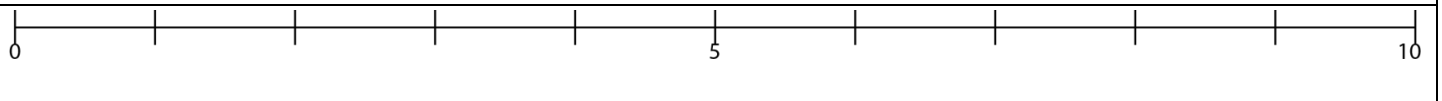
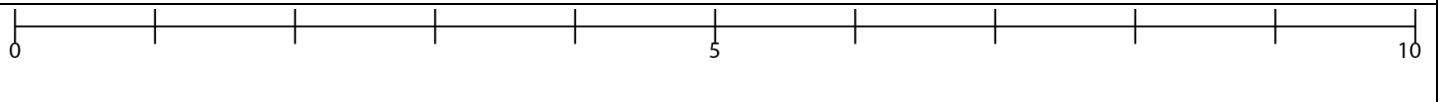
Would *knowing* the movement of an indoor pattern like this was *computer generated* make it seem any *less satisfactory* to you?

Please circle one of the following answers:

A. Yes, significantly less satisfying B. Yes, slightly less satisfying C. No, it would make no difference.

Question 7

On a scale of 0-10 (10 being most appropriate) please rate the appropriateness of this kind of movement in the following kinds of indoor spaces:

Open Plan Office	
Study	
Living Room	
Classroom	
Lobby	
Bedroom	
Waiting Room	
Dining Area	
Room with no View	
Windowless Room	

Question 8

On a scale of 0-10 (10 being the most effective), please rate the effectiveness of alternative ways of bringing nature and change into a windowless room (listed along the top row of the table below), according to the criteria listed in the left column.

Please write a number between 0 and 10 in each empty box in the matrix representing your estimate of the likely effectiveness of each potential method according to each criteria:

Windowless Room With: / Sense Of:	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
Connection to the Outside World								
Connection to Nature								
Change in the Space								
Calming Effect								

Question 9

Please use the six control dials on the black box to adjust Pattern E to your personal preference. The six different parameters affect each other, so please play around with each to find a pattern of movement that is most pleasing to you. Have fun!

When you have a pattern that you really like, please write them below and leave the settings as they are so that we can record them.

Wind Direction:	
Wind Frequency:	
Wind Speed:	
Branch Strength:	
Leaf Strength:	

Question 10

In a *windowless* room with a projected digital tree shadow of the kind you saw earlier, please rank the following conditions out of ten in terms of your preference (with 10 being most preferred):

A.	Wind-generated movement that is not controllable	
B.	Wind-generated movement that you can adjust	
C.	Computer generated movement that is not controllable	
D.	Computer-generated movement that you can adjust	

Additional Comments (Optional – answer whichever you please):

How much caffeine did you have today?

Would/did you find this distracting? How?

Would you use this? Where?

Would you change it? How?

Did you learn anything?

Any other questions I should be asking? Your answer?

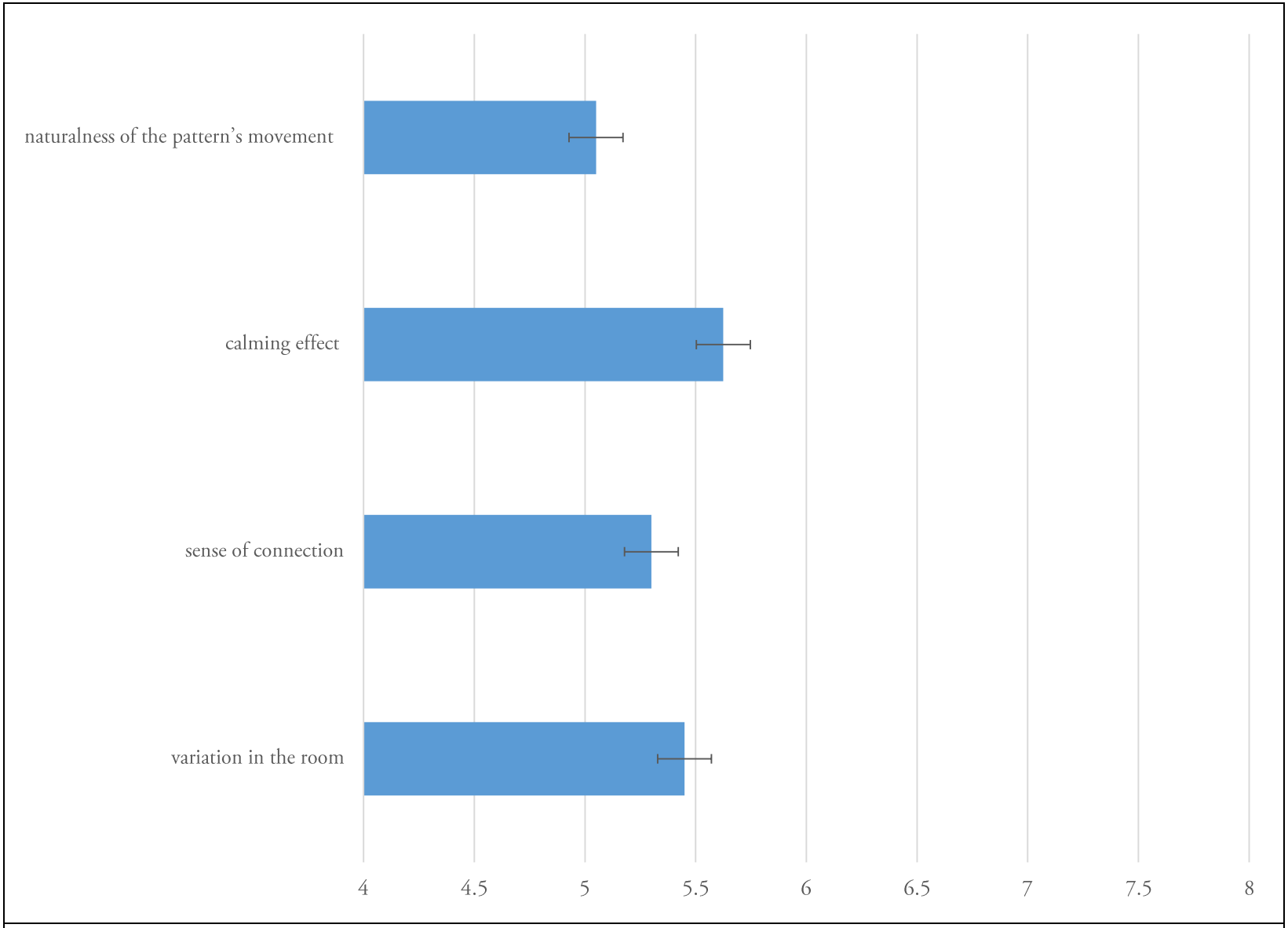
Any additional feedback is welcome.

Thank you

APPENDIX B

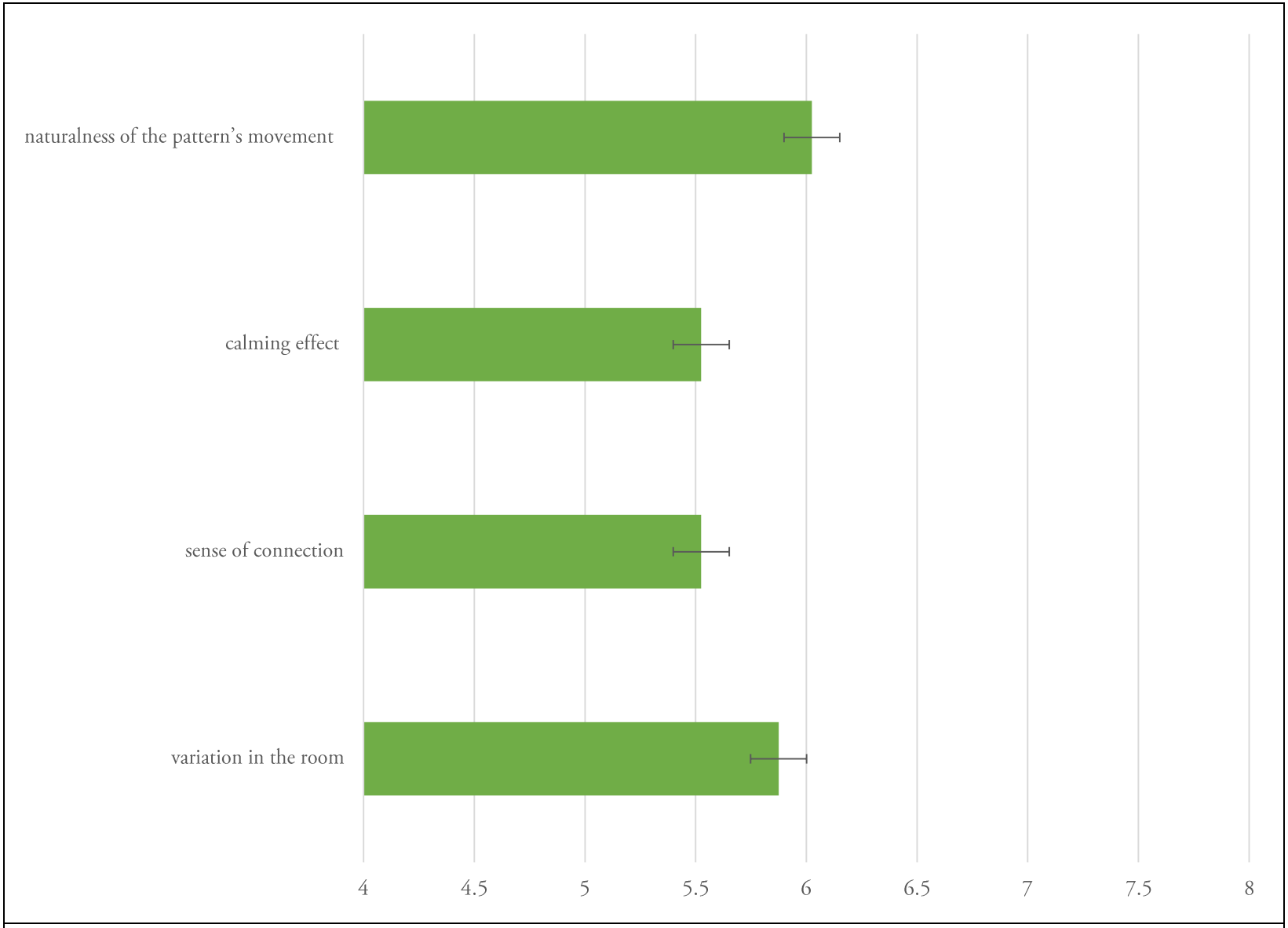
QUESTIONAIRE RESULTS AND CHARTS

Questionnaire Version 1 – Question1 - Pattern A : Artificially Generated Movement				
Subject #	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
803-01	3	6	8	8
803-03	8	10	9	10
803-04	6	5	3	3
803-05	5.5	8	6.5	7.5
806-11	5	7	7	5
807-12	4	5	6	7
807-14	7	7	8	6
808-16	0	0	0	3
808-18	3	4	5	3
809-20	4	5	4	2
809-22	5	3	6	4
813-24	6	6	4	3
813-26	7	3	3	3
814-29	6	5	4	6
814-30	8	10	7	7
815-31	6	4	6	7
815-34	7	7	9	6
816-35	7	7	8	6
816-37	5.5	2	3	2.5
816-39	6	2	6	2
Average	5.45	5.3	5.625	5.05



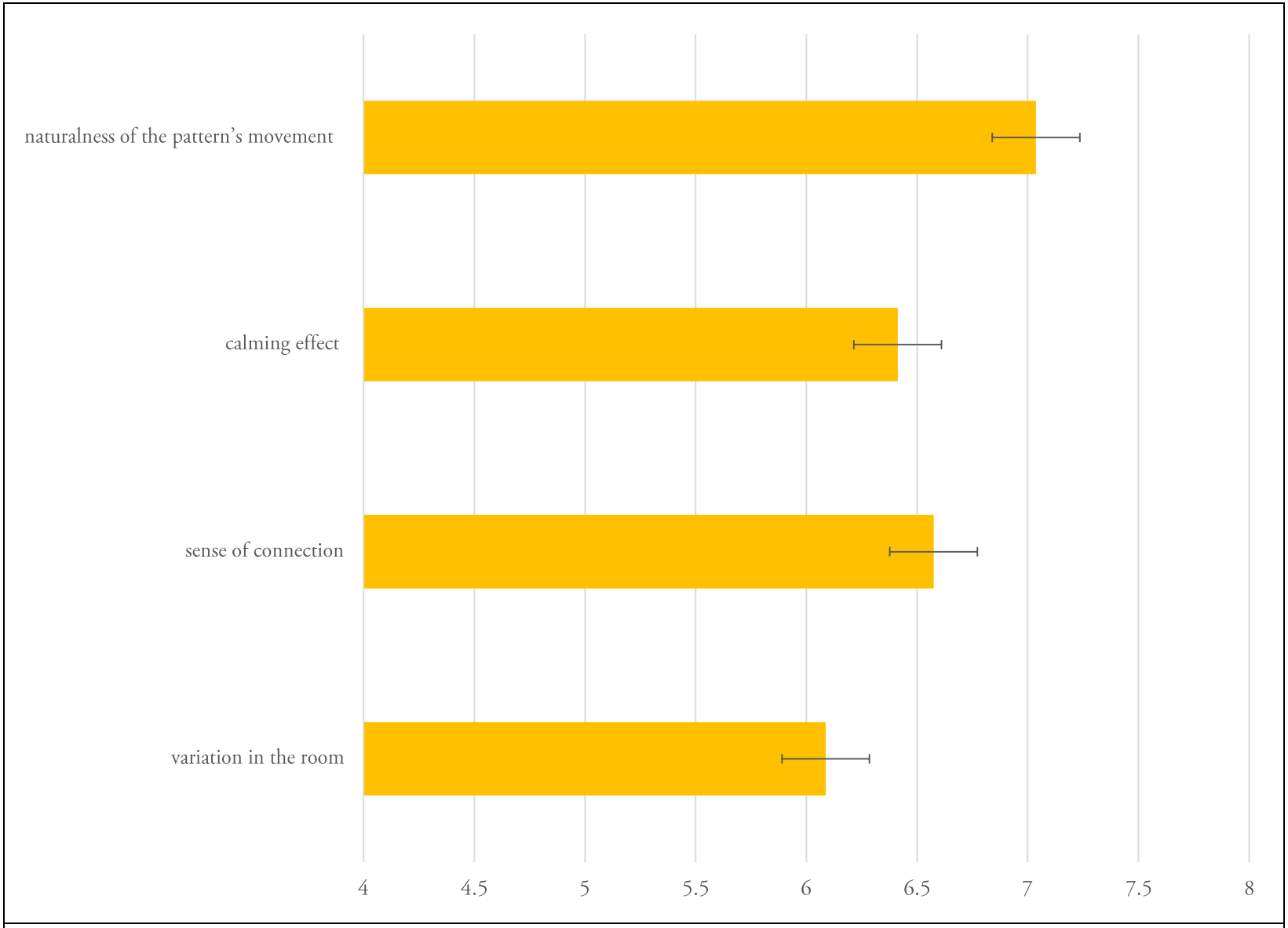
Questionnaire Version 1 – Question 1 - Pattern A : Artificially Generated Movement

Questionnaire Version 1 - Question 2 - Pattern B : Naturally Generated Movement				
	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
803-01	5	5	4	8
803-03	8	9	9	7
803-04	6	6	5	5
803-05	7.5	6.5	6.5	8.5
806-11	5	4	4	2
807-12	3	5	6	8
807-14	7	7	5	8
808-16	1	1	0	3
808-18	4	5	4	6
809-20	5	4	3	3
809-22	6	6	7	7
813-24	6	5	6	6
813-26	6	5	5	4
814-29	4	4	5	3
814-30	10	10	8	8
815-31	5	4	4	5
815-34	8	8	9	10
816-35	8	9	9	10
816-37	7	4	5	5
816-39	6	3	6	4
Average	5.875	5.525	5.525	6.025



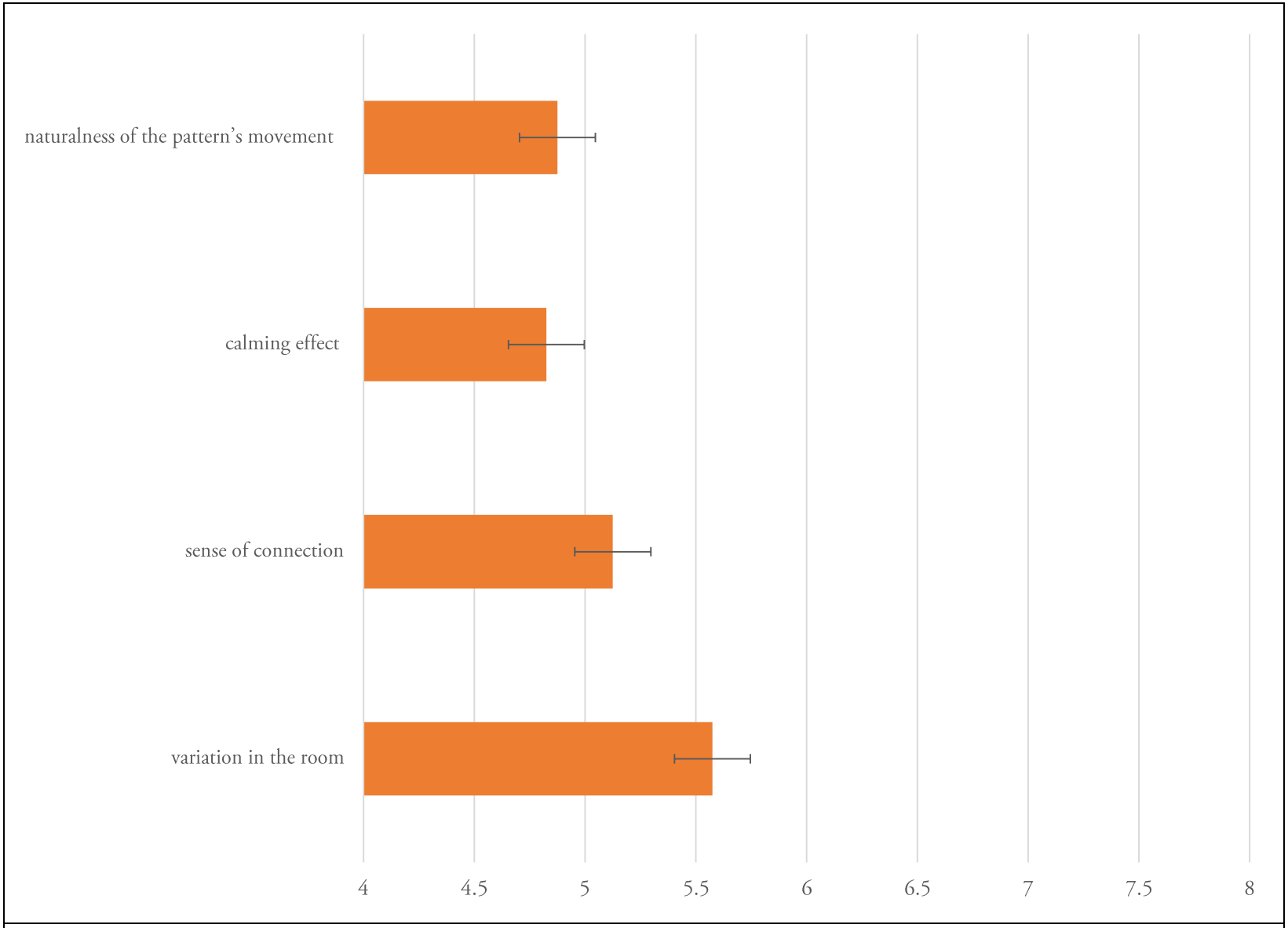
Questionnaire Version 1 - Question 2 - Pattern B : Naturally Generated Movement

Questionnaire Version 1 – Question 3 - Pattern C : Artificially Generated Movement Labeled as Natural				
	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
803-01	5	6	6	7
803-03	10	9	10	10
803-04	6	6	6	6
803-05	7.5	8.5	9.5	7.5
806-11	5	9	7	8
807-12	3	6	6	7
807-14	7	7	8	8
808-16	0	0	0	1
808-18	3	4	3	6
809-20	6	6	5	7
809-22	6	6	7.5	7
813-24	6	7	8	8
813-26	6	6	5	7
814-29	7	7	7	5
814-30	9	10	7	9
815-31	6	5	6	8
815-34	7	7	8	8
816-35	10	10	9	10
816-37	5.25	6	5.25	5.25
816-39	7	6	5	6
Average	6.0875	6.575	6.4125	7.0375



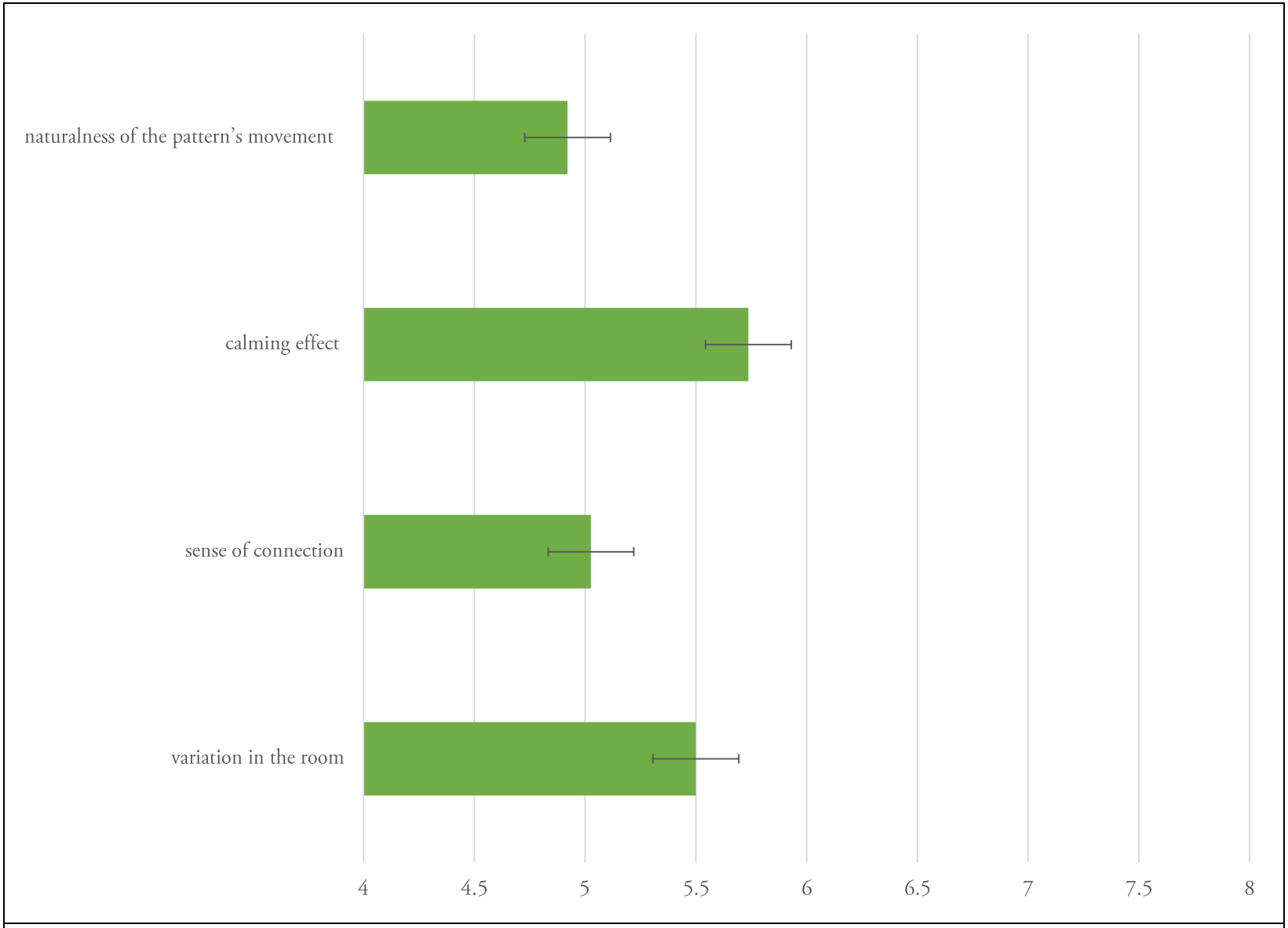
Questionnaire Version 1 – Question 3 - Pattern C : Artificially Generated Movement Labeled as Natural

Questionnaire Version 1 – Question 4 - Pattern D : Naturally Generated Movement Labeled as Artificial				
	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
803-01	6	6	7	7
803-03	9	9	7	7
803-04	6	6	5	5
803-05	6.5	6.5	5.5	7.5
806-11	5	4	3	2
807-12	5	6	5	7
807-14	7	7	7	8
808-16	0	0	0	0
808-18	4	4	3	4
809-20	4	2	2	2
809-22	6	5	6	6
813-24	5	5	4	6
813-26	4	4	3	3
814-29	4	5	3	2
814-30	10	10	9	9
815-31	6	5	5	4
815-34	7	7	7	7
816-35	6	4	5	4
816-37	5	4	5	5
816-39	6	3	5	2
Average	5.575	5.125	4.825	4.875



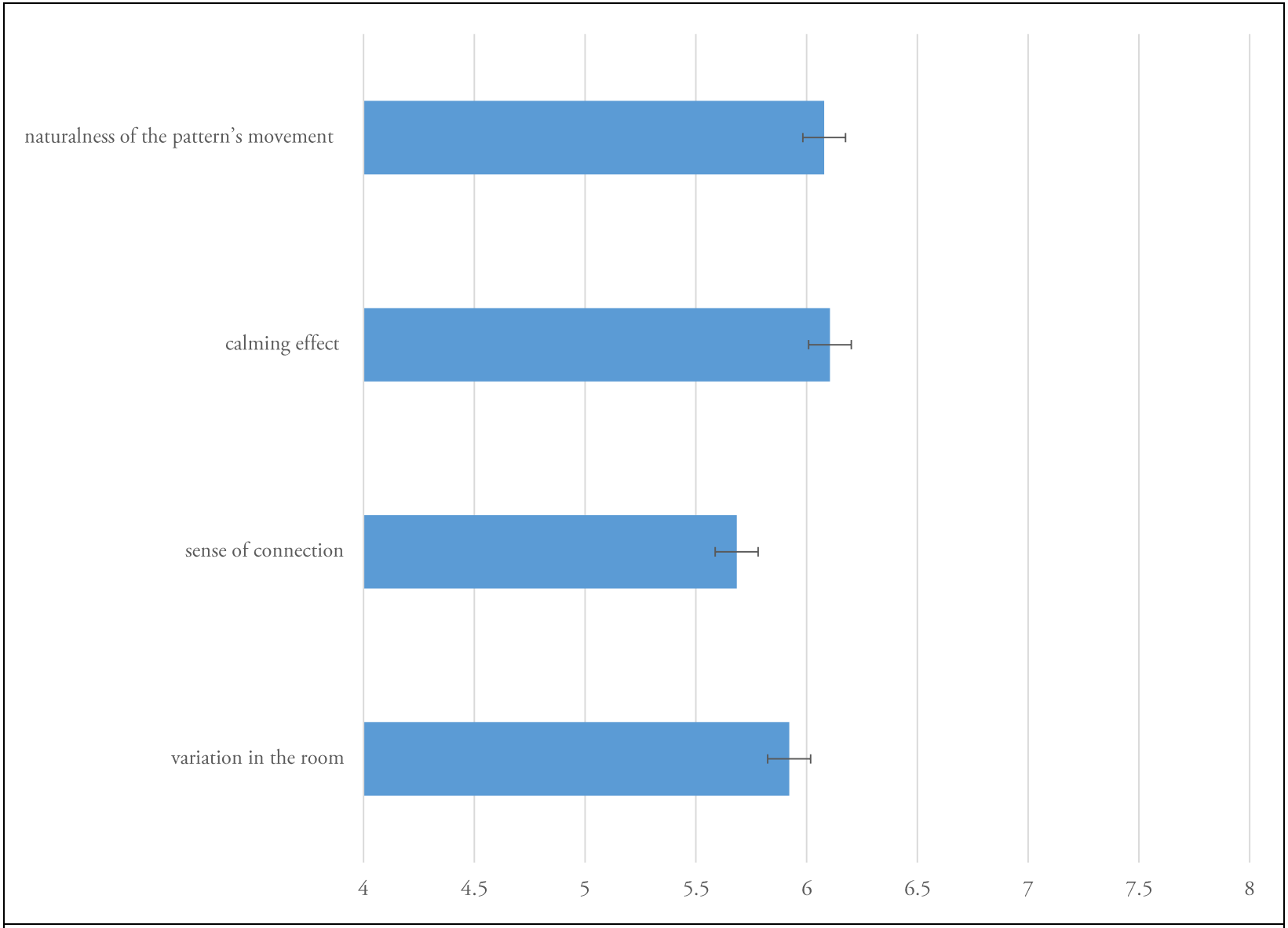
Questionnaire Version 1 – Question 4 - Pattern D : Naturally Generated Movement Labeled as Artificial

Questionnaire Version 2 – Question1 - Pattern A: Naturally Generated Movement				
	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
803-02	7	6	5	3
806-06	8	9	9	7
806-07	4	3	2	2
806-08	4	5	7	5
806-09	6	6	4	7
806-10	3	7.5	8	5
807-13	5	6	6	7
807-15	5	4	10	4
808-17	7	5	5	4
809-19	7	8	6	7
809-21	8	6	7	4
813-23	5	3	7	7
813-25	7	6	8	8.5
814-27	4.5	5	5	3
814-28	5	3	9	6
815-32	3	3	3	5
815-33	6	4	3	4
816-36	4	2	1	3
816-38	6	4	4	2
Average	5.5	5.026315789	5.736842105	4.921052632



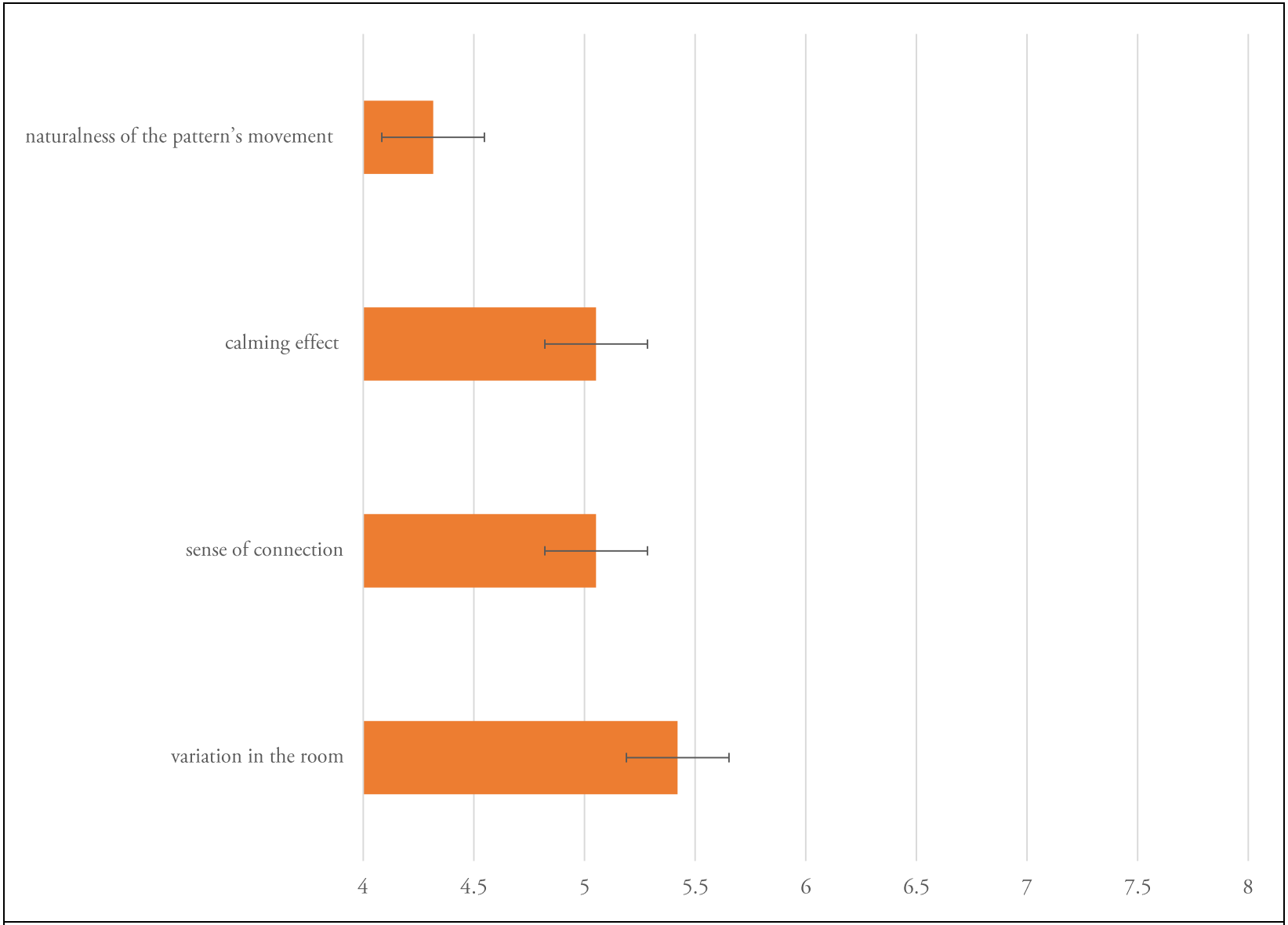
Questionnaire Version 2 – Question 1 - Pattern A: Naturally Generated Movement

Questionnaire Version 2 – Question 2 - Pattern B: Artificially Generated Movement				
	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
803-02	7	6	7	8
806-06	5	5	7	7
806-07	5	4	4	4
806-08	6	7	7	7
806-09	5	6	4	5
806-10	5	8	9	9
807-13	5	5	5	6
807-15	6	5	10	4
808-17	7	6	6	6.5
809-19	5	4	4	4
809-21	8	8	9	8
813-23	6	7	8	8
813-25	6.5	5	4	4
814-27	5	6	4	4
814-28	7	7	9	7
815-32	6	5	7	8
815-33	6	4	4	5
816-36	6	5	4	6
816-38	6	5	4	5
Average	5.921052632	5.684210526	6.105263158	6.078947368



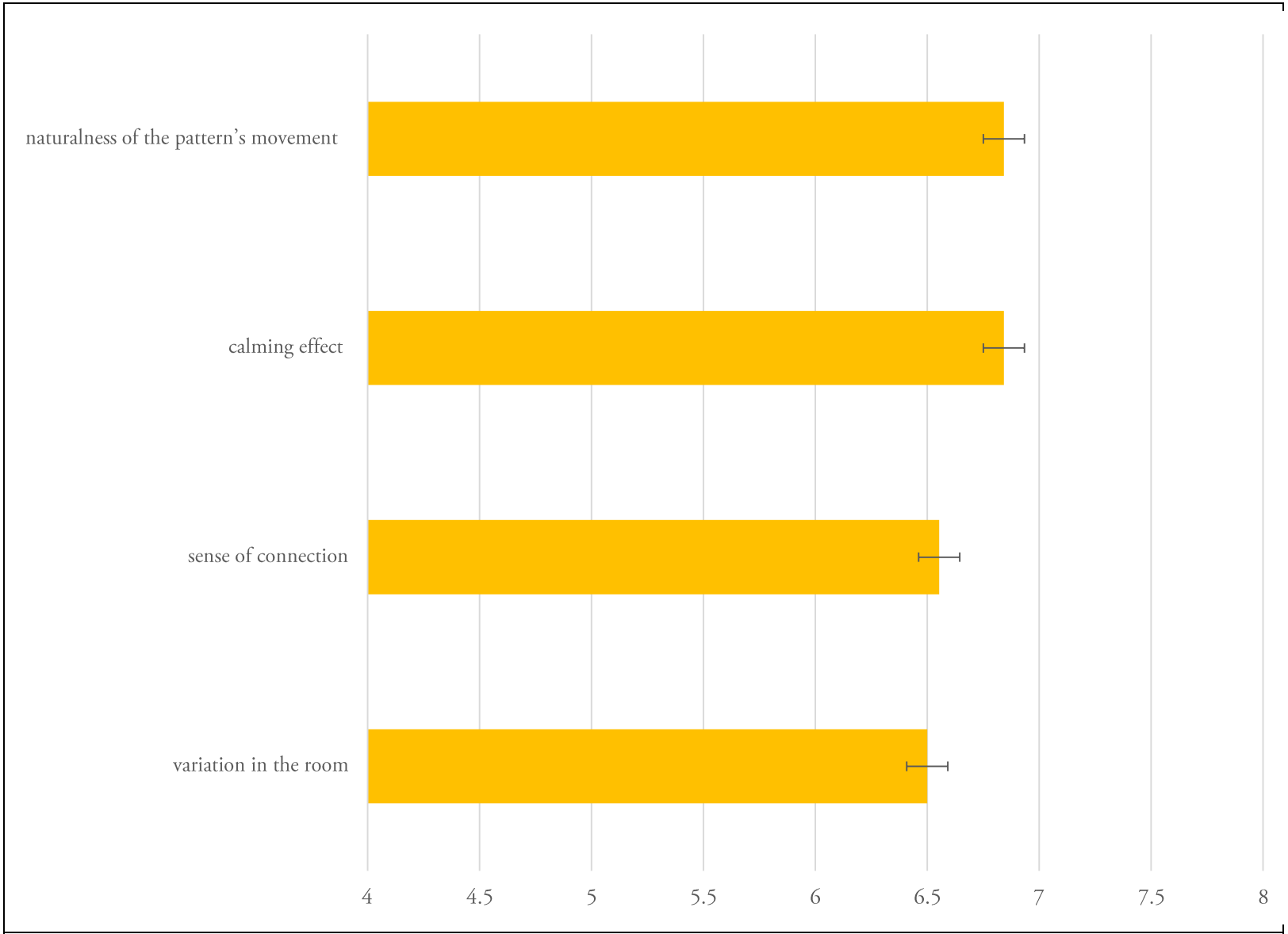
Questionnaire Version 2 – Question 2 - Pattern B: Artificially Generated Movement

Questionnaire Version 2 – Question 3 - Pattern C: Naturally Generated Movement Labeled Artificial				
	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
803-02	7	6	7	4
806-06	7	5	3	5
806-07	4	4	3	4
806-08	5	6	6	4
806-09	6	7	5	5
806-10	9	8	4	2
807-13	4	4	4	3
807-15	6	5	10	4
808-17	4	3	3	3
809-19	4	7	4	7
809-21	2	3	3	3
813-23	4	4	5	4
813-25	8	7	8	8
814-27	6	6	5	6
814-28	7	7	8	6
815-32	3	4	5	4
815-33	6	4	6	2
816-36	4	1	2	2
816-38	7	5	5	6
Average	5.421052632	5.052631579	5.052631579	4.315789474



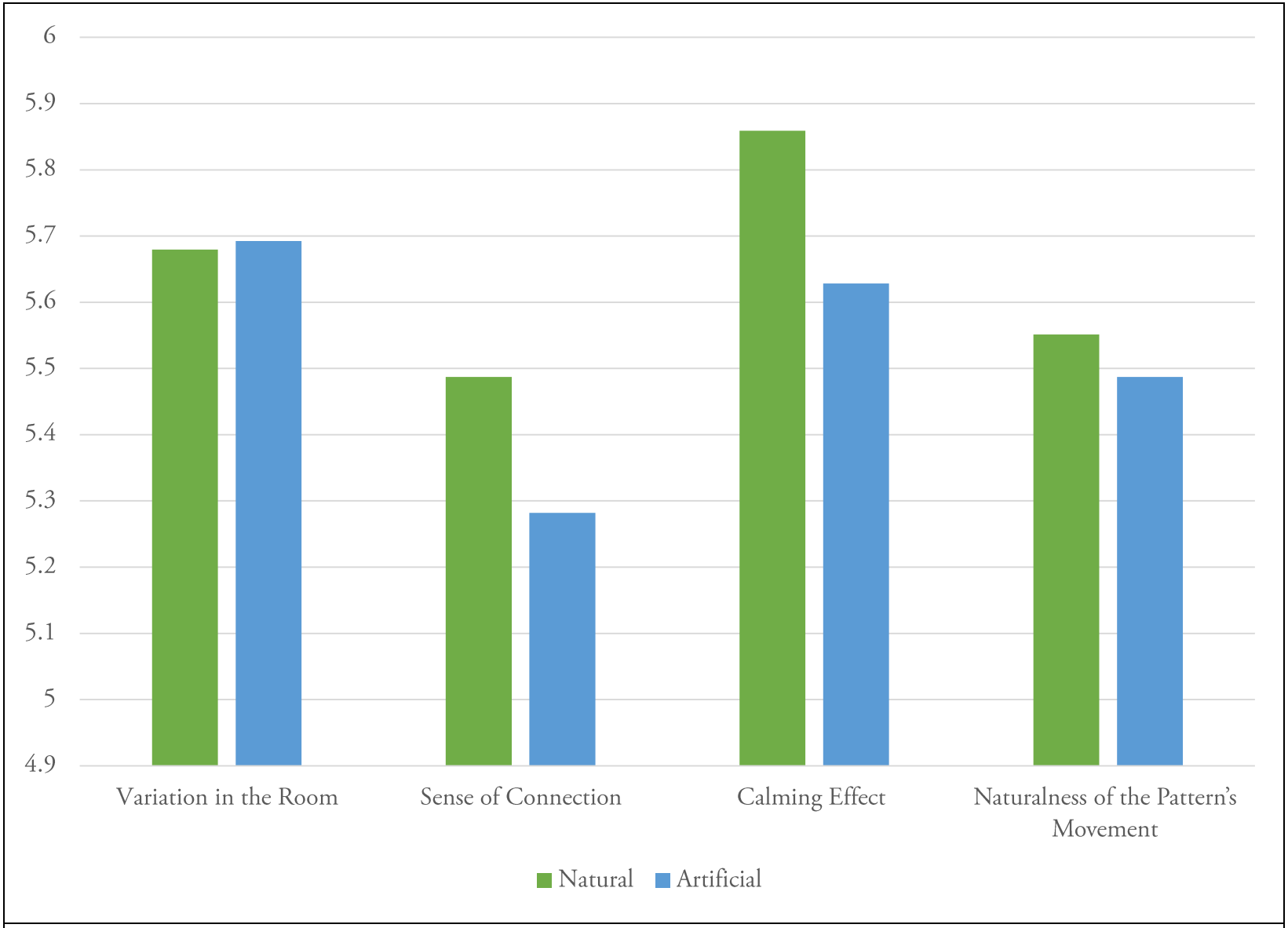
Questionnaire Version 2 – Question 3 - Pattern C: Naturally Generated Movement Labeled Artificial

Questionnaire Version 2 – Question 4 - Pattern D: Artificially Generated Movement Labeled Natural				
	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
803-02	7	5	6	6
806-06	5	7	7	7
806-07	5	6	5	5
806-08	8	8	8	7
806-09	7	7	5	6
806-10	8	9	10	10
807-13	5	6	7	7
807-15	6	4.5	10	5
808-17	5	5	5	4
809-19	5	9	7	9
809-21	9	9	8	9
813-23	7	8	8	8
813-25	7.5	8	7	9
814-27	7	6	7	7
814-28	8	8	9	8
815-32	5	4	4	5
815-33	7	5	7	7
816-36	6	5	6	6
816-38	6	5	4	5
Average	6.5	6.552631579	6.842105263	6.842105263

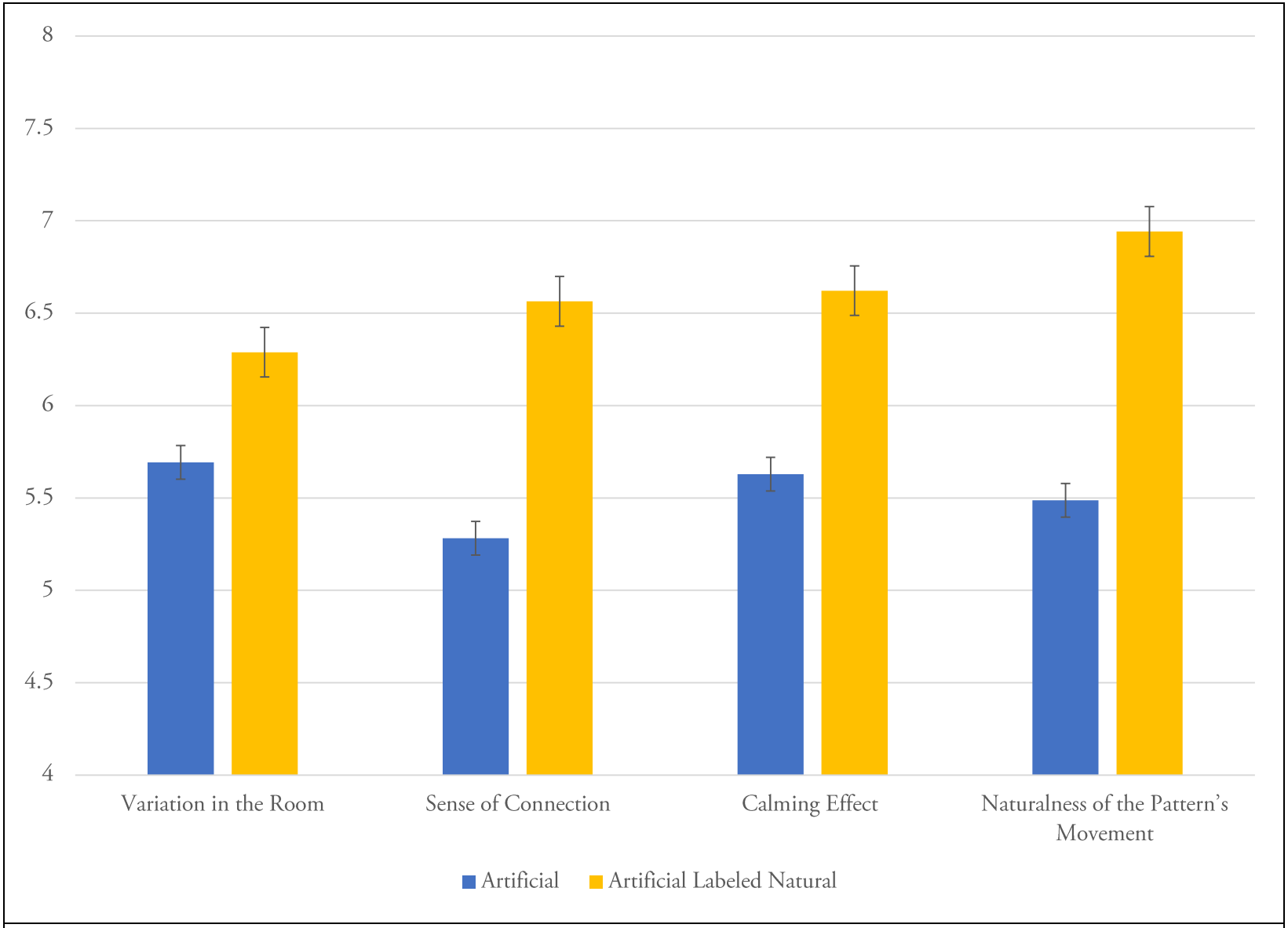


Questionnaire Version 2 – Question 4 - Pattern D: Artificially Generated Movement Labeled Natural

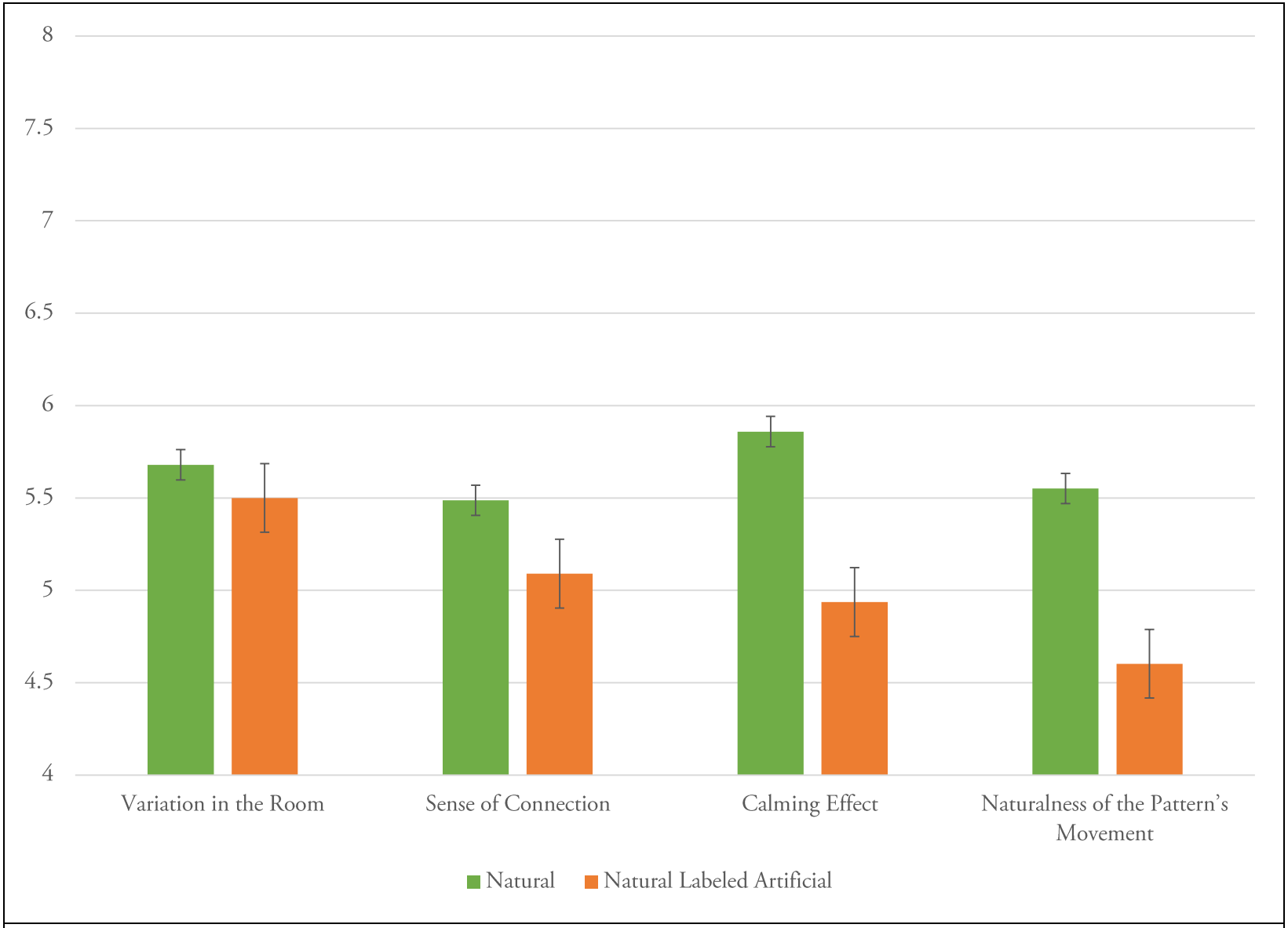
Consolidated Preference Data Questions 1-4				
	VARIATION IN THE ROOM	SENSE OF CONNECTION	CALMING EFFECT	NATURALNESS OF THE PATTERN'S MOVEMENT
Pattern A (Artificial)	5.45	5.3	5.625	5.05
Pattern A (Natural)	5.5	5.026315789	5.736842105	4.921052632
Pattern B (natural)	5.875	5.525	5.525	6.025
Pattern B (artificial)	5.921052632	5.684210526	6.105263158	6.078947368
Pattern C (Artificial Labeled natural)	6.0875	6.575	6.4125	7.0375
Pattern C (Natural Labeled Artificial)	5.421052632	5.052631579	5.052631579	4.315789474
Pattern D (Natural Labeled Artificial)	5.575	5.125	4.825	4.875
Pattern D (Artificial labeled natural)	6.5	6.552631579	6.842105263	6.842105263
Natural	5.679487179	5.487179487	5.858974359	5.551282051
Artificial	5.692307692	5.282051282	5.628205128	5.487179487
Artificial Labeled Natural	6.288461538	6.564102564	6.621794872	6.942307692
Natural Labeled Artificial	5.5	5.08974359	4.935897436	4.602564103



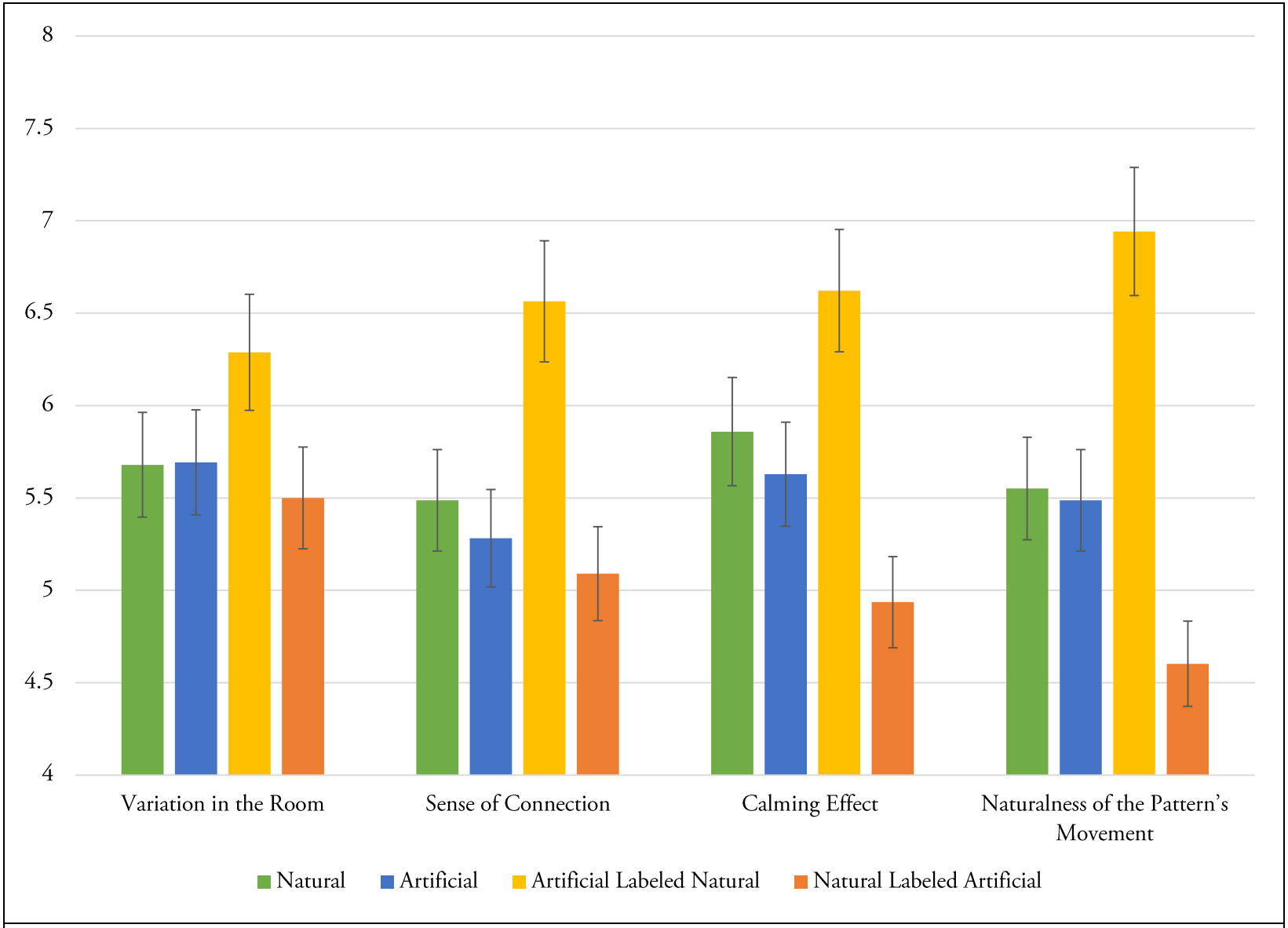
Consolidated Preference Data Questions 1-4: Artificial and Naturally Generated Movement Comparison



Consolidated Preference Data Questions 1-4: The Effect of Falsely Labeling Artificially-Generated Movement as Natural

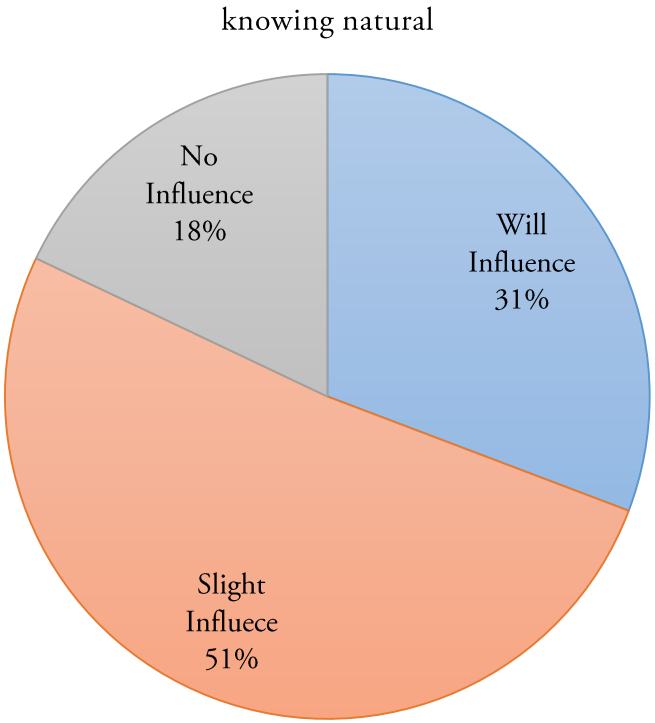
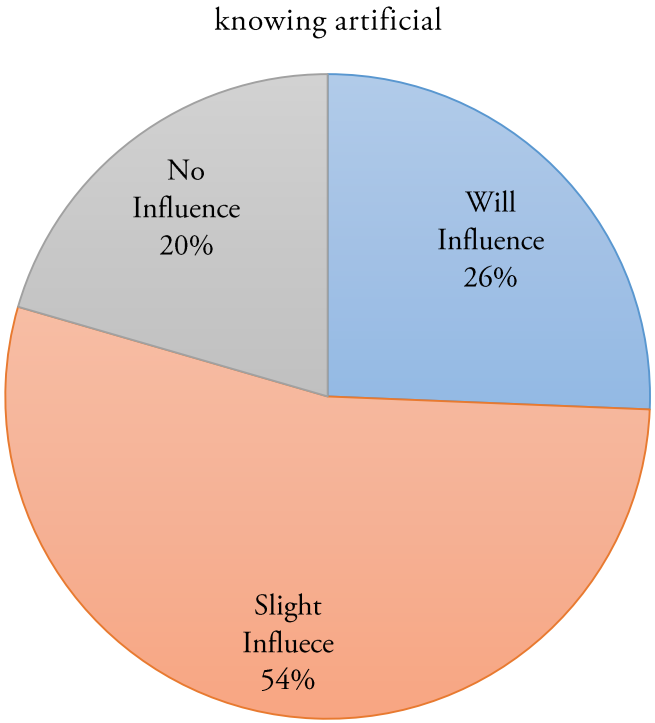


Consolidated Preference Data Questions 1-4: The Effect of Falsely Labeling Naturally-Generated Movement as Artificial



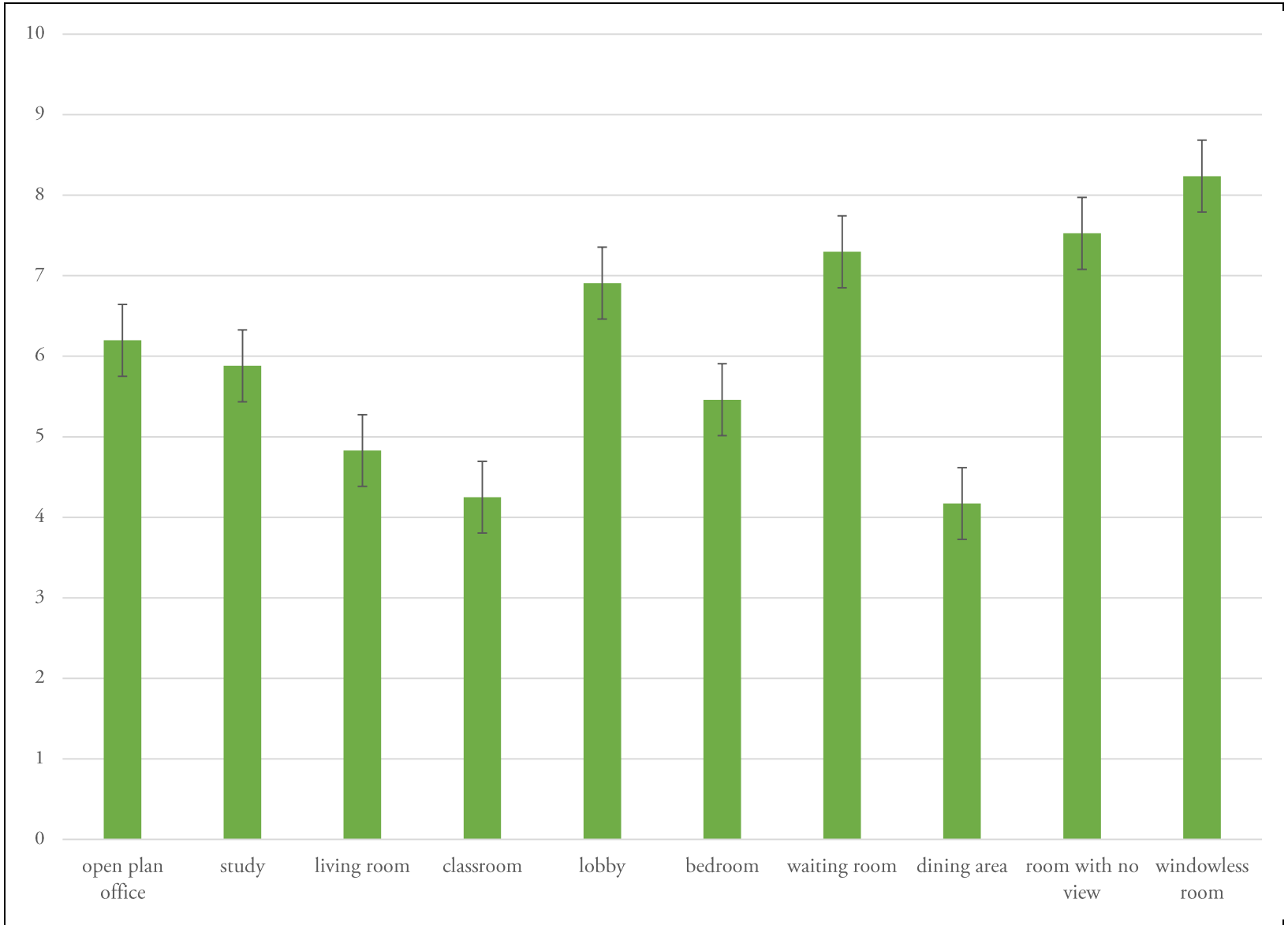
Consolidated Preference Data Questions 1-4

Questions 5&6: Self-Assessment of the Likely Effect of Knowing the Source of Movement was Natural or Artificial					
	KNOWING NATURAL	KNOWING ARTIFICIAL		KNOWING NATURAL	KNOWING ARTIFICIAL
803-01	b	c	809-21	a	a
803-02	a	a	809-22	b	b
803-03	b	b	813-23	b	b
803-04	a	b	813-24	c	a
803-05	c	c	813-25	b	b
806-06	a	b	813-26	b	b
806-07	a	b	814-27	b	c
806-08	a	b	814-28	a	b
806-09	c	c	814-29	a	a
806-10	b	b	814-30	b	c
806-11	b	b	815-31	b	a
807-12	b	b	815-32	b	b
807-13	a	b	815-33	a	a
807-14	b	b	815-34	b	b
807-15	b	a	816-35	a	b
808-16	c	c	816-36	b	b
808-17	a	a	816-37	b	a
808-18	c	a	816-38	c	c
809-19	b	b	816-39	c	c
809-20	b	b			

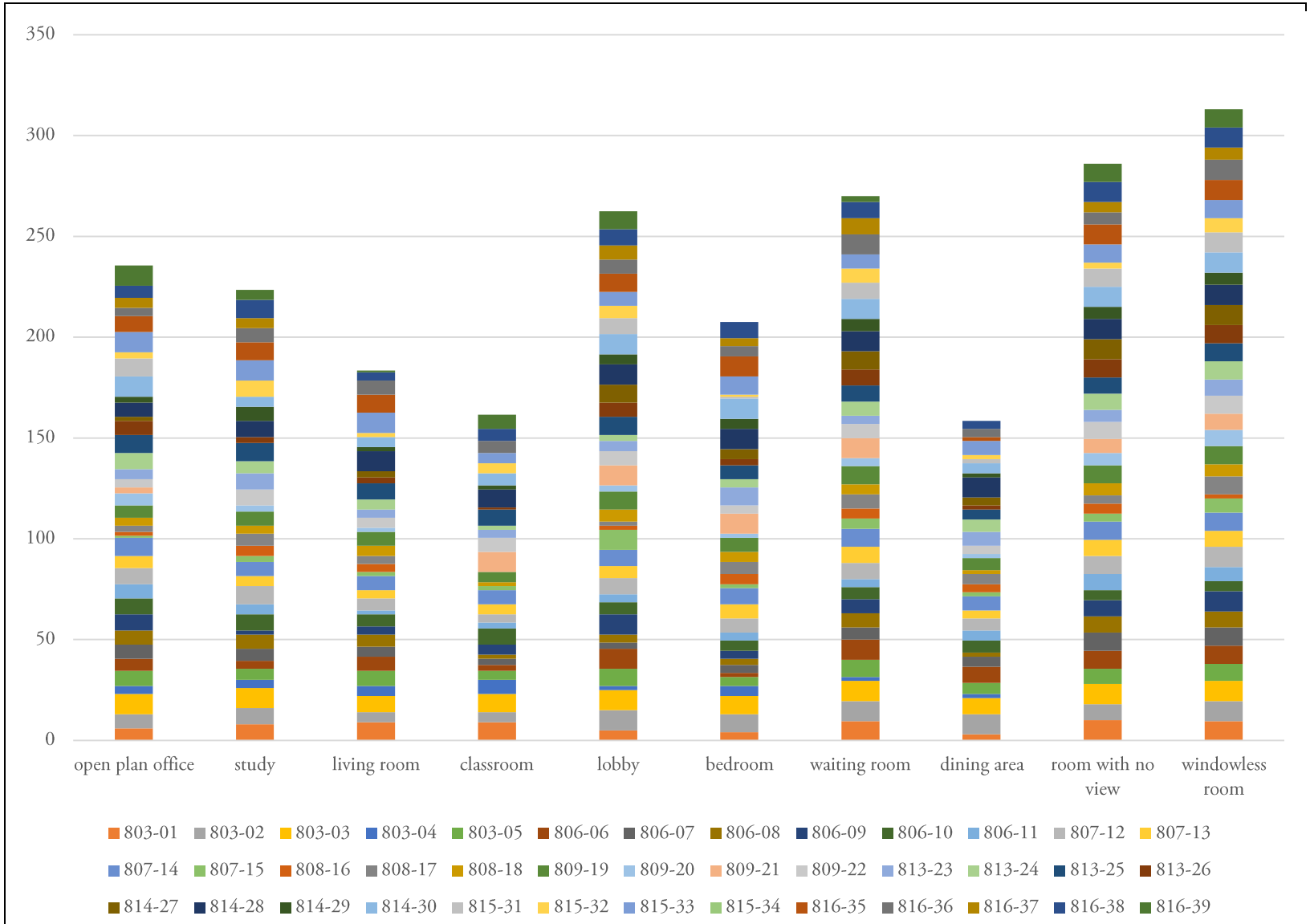
Questions 5&6: Self-Assessment of the Likely Effect of Knowing the Source of Movement was Natural or Artificial	
	

Question 7: Subject Ratings of Animated Digital Tree Shadow Appropriateness in Different Rooms										
	OPEN PLAN OFFICE	STUDY	LIVING ROOM	CLASS-ROOM	LOBBY	BED-ROOM	WAIT-ING ROOM	DIN-ING AREA	ROOM W/ NO VIEW	WIN-DOW-LESS ROOM
803-01	6	8	9	9	5	4	9.5	3	10	9.5
803-02	7	8	5	5	10	9	10	10	8	10
803-03	10	10	8	9	10	9	10	8	10	10
803-04	4	4	5	7	2	5	2	2	0	0
803-05	7.5	5.5	7.5	4.5	8.5	4.5	8.5	5.5	7.5	8.5
806-06	6	4	7	3	10	2	10	8	9	9
806-07	7	6	5	3	3	4	6	5	9	9
806-08	7	7	6	2	4	3	7	2	8	8
806-09	8	2	4	5	10	4	7	0	8	10
806-10	8	8	6	8	6	5	6	6	5	5
806-11	7	5	2	3	4	4	4	5	8	7
807-12	8	9	6	4	8	7	8	6	9	10
807-13	6	5	4	5	6	7	8	4	8	8
807-14	9	7	7	7	8	8	9	7	9	9
807-15	1	3	2	2	10	2	5	2	4	7
808-16	2	5	4	0	2	5	5	4	5	2
808-17	3	6	4	0	2	6	7	5	4	9
808-18	4	4	5	2	6	5	5	2	6	6
809-19	6	7	7	5	9	7	9	6	9	9
809-20	6	3	2	0	3	2	4	2	6	8

Question 7: Subject Ratings of Animated Digital Tree Shadow Appropriateness in Different Rooms Continued										
	OPEN PLAN OFFICE	STUDY	LIVING ROOM	CLASS-ROOM	LOBBY	BED-ROOM	WAIT-ING ROOM	DIN-ING AREA	ROOM W/ NO VIEW	WIN-DOW-LESS ROOM
809-21	3	0	0	10	10	10	10	0	7	8
809-22	4	8	5	7	7	4	7	4	8.5	9
813-23	5	8	4	4	5	9	4	7	6	8
813-24	8	6	5	2	3	4	7	6	8	9
813-25	9	9	8	8	9	7	8	5	8	9
813-26	7	3	3	1	7	3	8	2	9	9
814-27	2	0	3	0	9	5	9	4	10	10
814-28	7	8	10	9	10	10	10	10	10	10
814-29	3	7	2	2	5	5	6	2	6	6
814-30	10	5	5	6	10	10	10	5	10	10
815-31	9	0	0	0	8	1	8	2	9	10
815-32	3	8	2	5	6	1	7	2	3	7
815-33	10	10	10	5	7	9	7	7	9	9
815-34										
816-35	8	9	9	0	9	10	-	2	10	10
816-36	4	7	7	6	7	5	10	4	6	10
816-37	5	5	0	0	7	4	8	0	5	6
816-38	6	9	4	6	8	8	8	4	10	10
816-39	10	5	1	7	9	0	3	0	9	9
Average	6.19736 8421	5.88157 8947	4.82894 7368	4.25	6.90789 4737	5.46052 6316	7.29729 7297	4.17105 2632	7.52631 5789	8.23684 2105



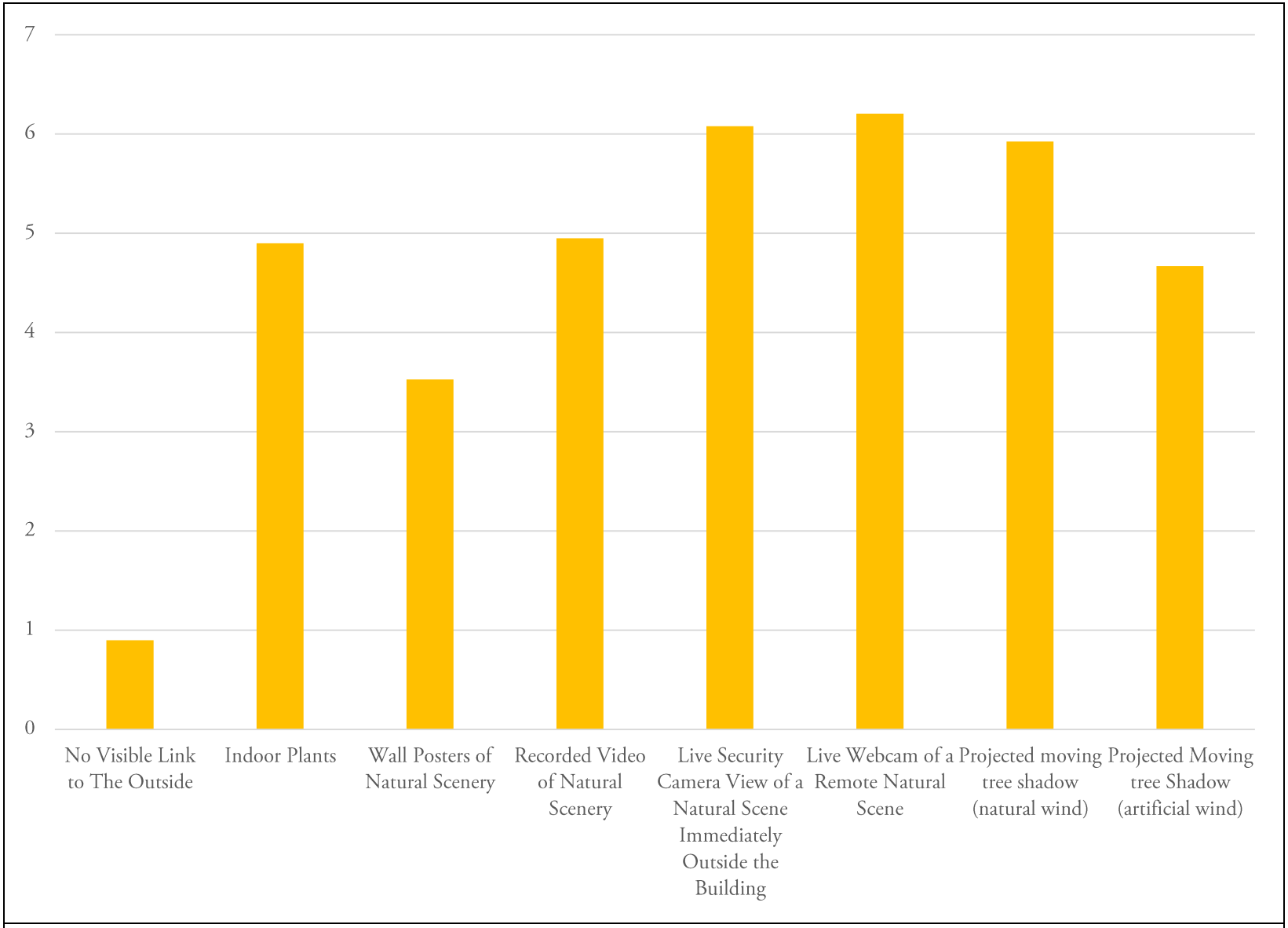
Question 7: Subject Ratings of Animated Digital Tree Shadow Appropriateness in Different Rooms



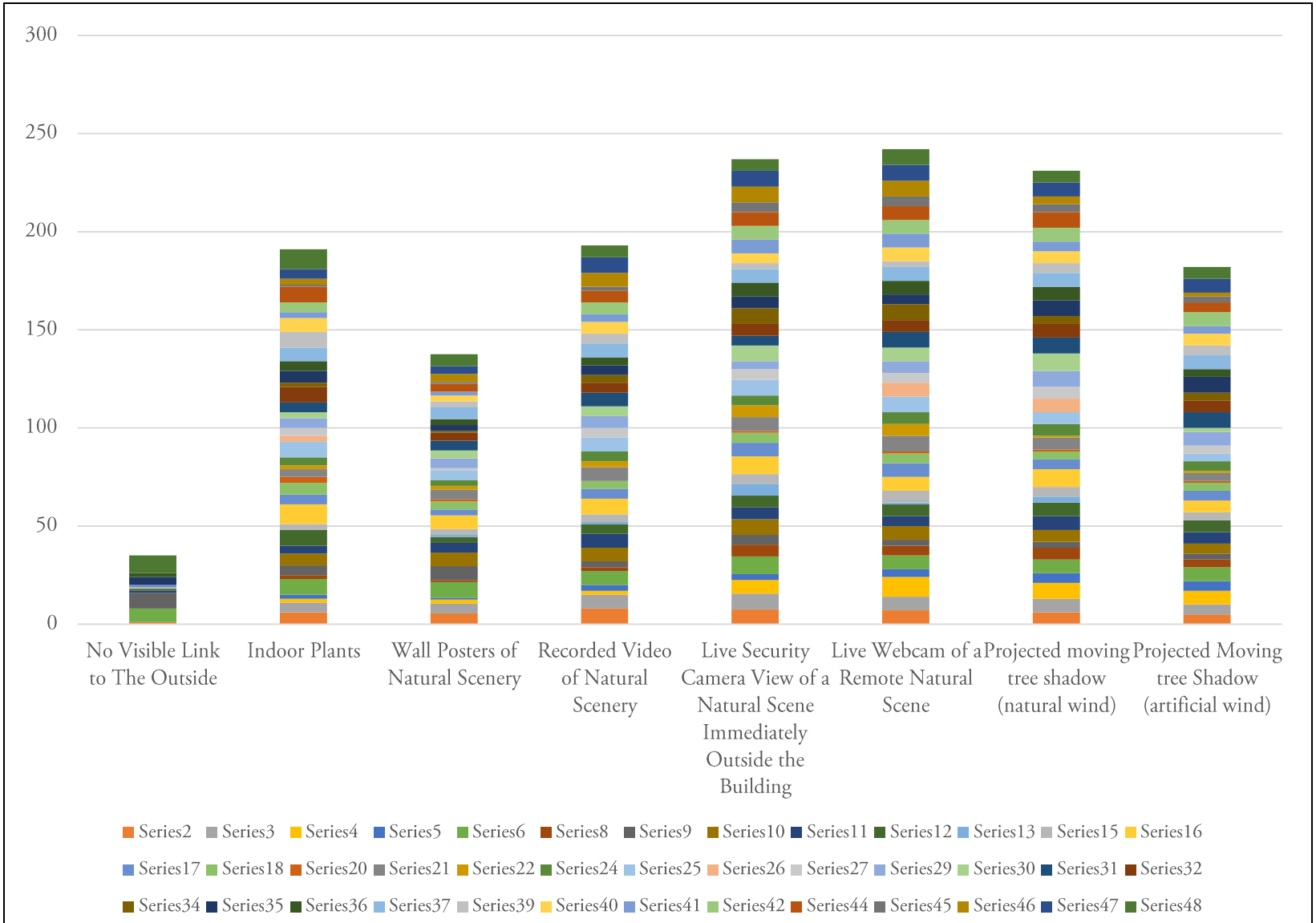
Question 7: Subject Ratings of Animated Digital Tree Shadow Appropriateness in Different Rooms Totals

Question 8: Comparison of Methods - Sense of Connection to the Outside								
	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
803-01	1	6	5.5	8	7.5	7	6	5
803-02	0	5	5	7	8	7	7	5
803-03	0	2	2	2	7	10	8	7
803-04	0	2	1	3	3	4	5	5
803-05	7	8	8	7	9	7	7	7
806-06	0	2	1	2	6	5	6	4
806-07	8	5	7	3	5	3	3	3
806-08	0	6	7	7	8	7	6	5
806-09	1	4	5	7	6	5	7	6
806-10	1	8	3	5	6	6	7	6
806-11	0	0	1	1	6	1	3	0
807-12	1	3	3	4	5	6	5	4
807-13	0	10	7	8	9	7	9	6
807-14	1	5	3	5	7	7	5	5
807-15	0	6	4	4	5	5	4	4
808-16	0	3	1	0	1	1	1	1
808-17	0	4	5	7	7	8	6	4
808-18	0	2	2	3	6	6	1	1
809-19	0	4	3	5	5	6	6	5
809-20	0	8	5	7	8	8	6	4
809-21	0	3	0	0	0	7	7	0
809-22	0	4	1	5	5.5	5	6	4

Question 8: Comparison of Methods - Sense of Connection to the Outside Continued								
	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
813-23	0	5	5	6	4	6	8	7
813-24	0	3	4	5	8	7	9	2
813-25	0	5	5	7	5	8	8	8
813-26	0	8	4	5	6	6	7	6
814-27	0	2	1	4	8	8	4	4
814-28	4	6	3	5	6	5	8	8
814-29	2	5	3	4	7	7	7	4
814-30	0	7	6	7	7	7	7	7
815-31	0	8	3	5	3	3	5	5
815-32	0	7	3	6	5	7	6	6
815-33	0	3	2	4	7	7	5	4
815-34	0	5	0	6	7	7	7	7
816-35	0	8	4	6	7	7	8	5
816-36	0	1	1	2	5	5	4	3
816-37	0	3	4	7	8	8	4	2
816-38	0	5	4	8	8	8	7	7
816-39	9	10	6	6	6	8	6	6
Average	0.897435897	4.897435897	3.525641026	4.948717949	6.076923077	6.205128205	5.923076923	4.666666667



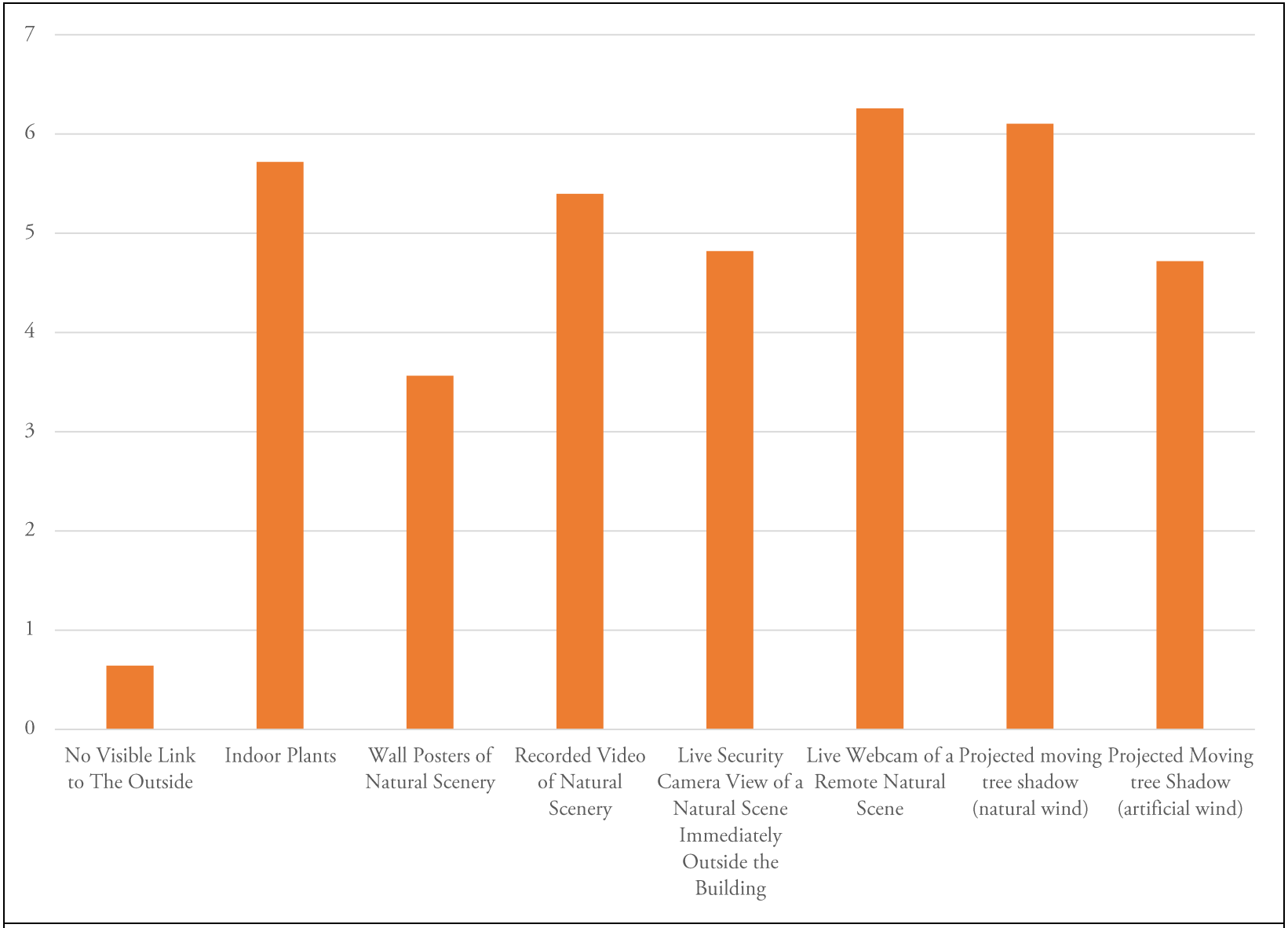
Question 8: Comparison of Methods - Sense of Connection to the Outside - Average Ratings



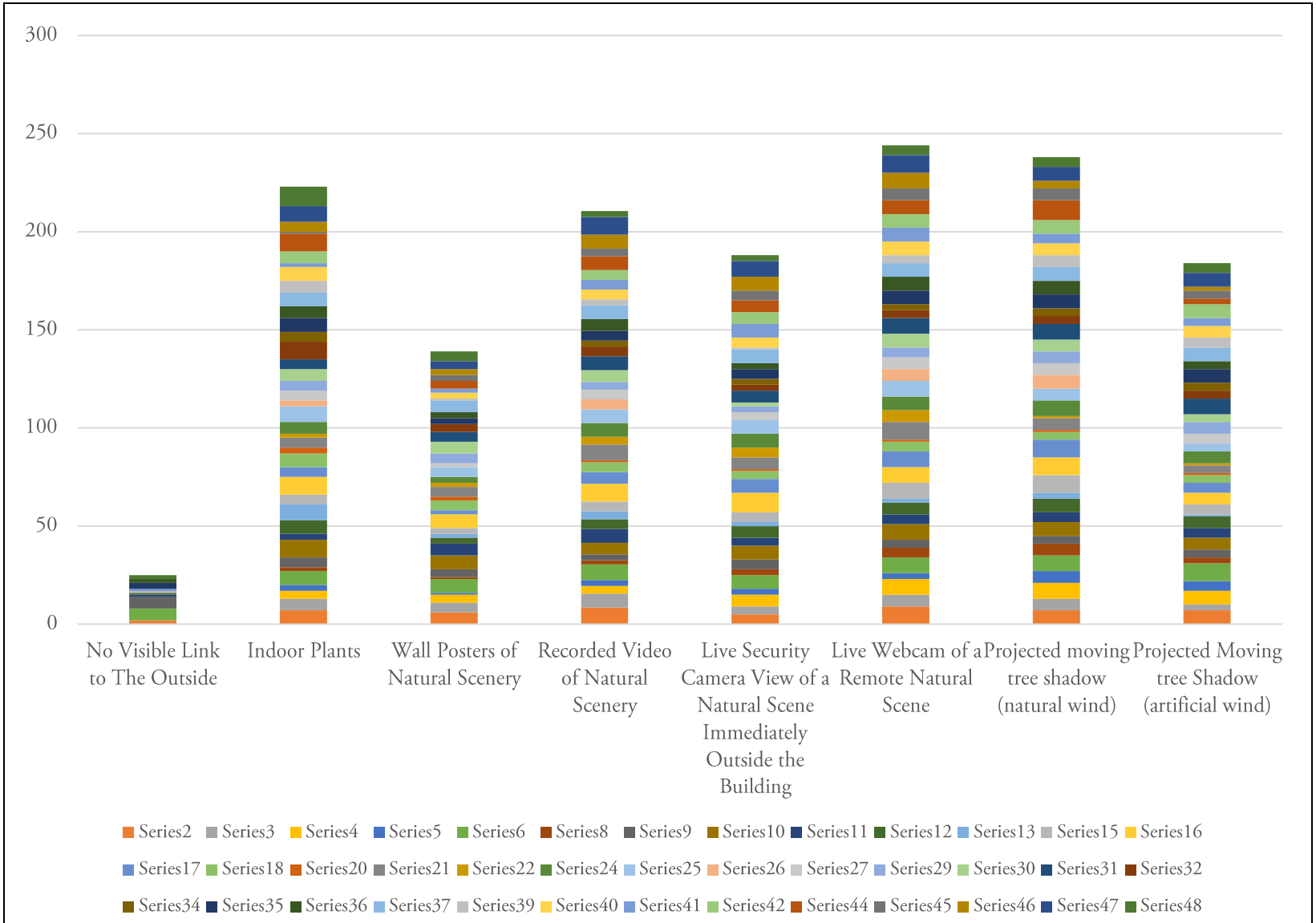
Question 8: Comparison of Methods - Sense of Connection to the Outside - Total Ratings

Question 8: Comparison of Methods - Sense of Connection to Nature								
	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
803-01	2	7	6	8.5	5	9	7	7
803-02	0	6	5	7	4	6	6	3
803-03	0	4	4	4	6	8	8	7
803-04	0	3	1	3	3	3	6	5
803-05	6	7	7	8	7	8	8	9
806-06	0	2	1	2	3	5	6	3
806-07	6	5	4	3	5	4	4	4
806-08	0	9	7	6	7	8	7	6
806-09	1	3	6	7	4	5	5	5
806-10	1	7	3	5	6	6	7	6
806-11	0	8	2	4	2	2	3	1
807-12	1	5	3	5	5	8	9	5
807-13	0	9	7	9	10	8	9	6
807-14	1	5	2	6	7	8	9	5
807-15	0	7	5	5	4	5	4	4
808-16	0	3	2	1	1	1	1	1
808-17	0	5	5	8	6	9	6	4
808-18	0	2	2	4	5	6	1	1
809-19	0	6	3	7	7	7	8	6
809-20	0	8	5	7	7	8	6	4
809-21	0	3	0	5	0	6	7	0

Question 8 – Comparison of Methods - Sense of Connection to Nature Continued								
	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
809-22	0	5	2	5	4	6	6	5
813-23	0	5	5	4	3	5	6	6
813-24	0	6	6	6	2	7	6	4
813-25	0	5	5	7	6	8	8	8
813-26	0	9	4	5	3	4	4	4
814-27	0	5	0	3	3	3	4	4
814-28	3	7	3	5	5	7	7	7
814-29	2	6	3	6	3	7	7	4
814-30	0	7	6	7	7	7	7	7
815-31	0	6	1	3	1	4	6	5
815-32	0	7	3	5	5	7	6	6
815-33	0	2	2	5	7	7	5	4
815-34	0	6	0	5	6	7	7	7
816-35	0	9	4	7	6	7	10	3
816-36	0	1	3	4	5	6	6	4
816-37	0	5	3	7	7	8	4	2
816-38	0	8	4	9	8	9	7	7
816-39	2	10	5	3	3	5	5	5
Average	0.641025641	5.717948718	3.564102564	5.397435897	4.820512821	6.256410256	6.102564103	4.717948718



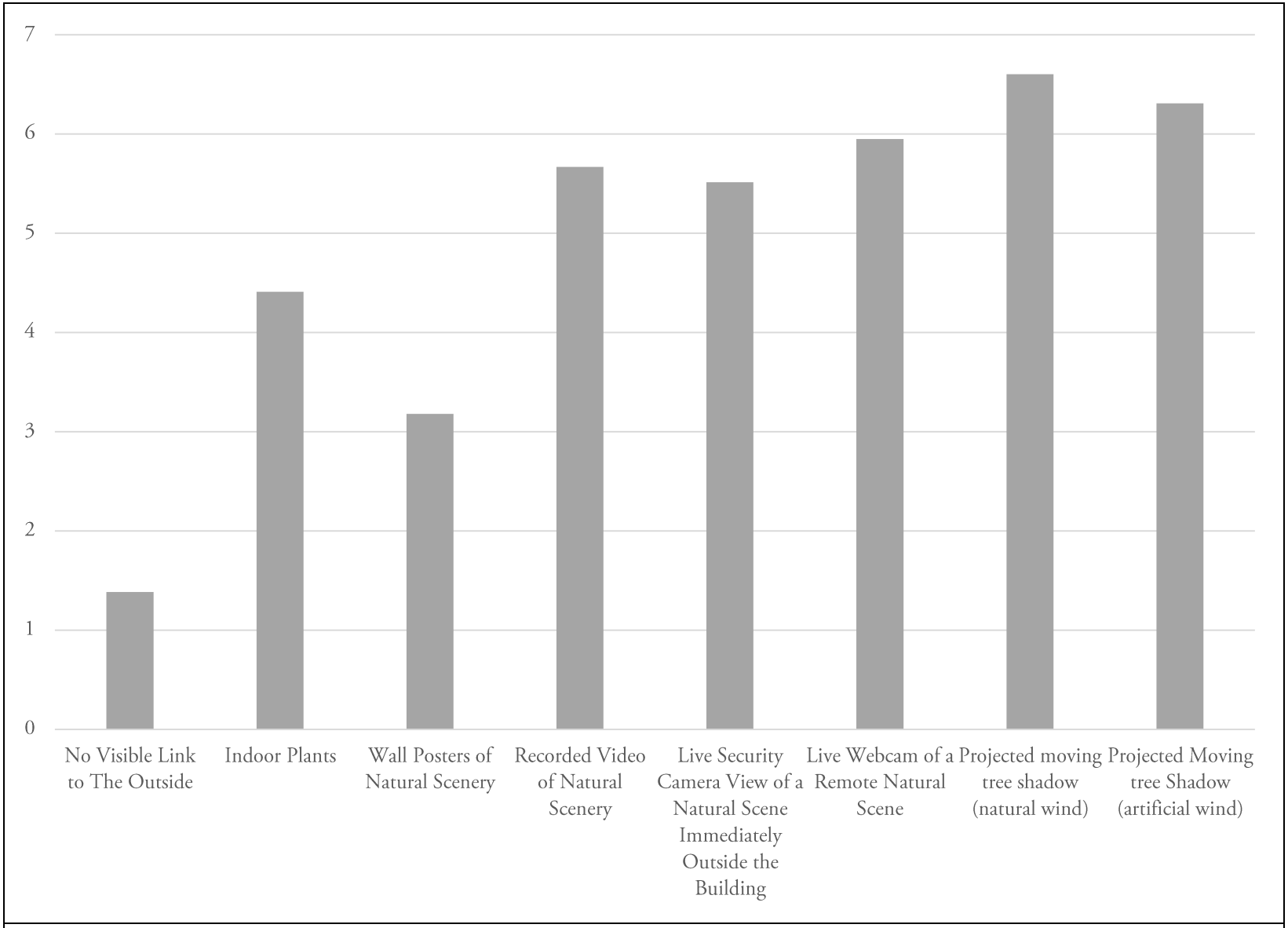
Question 8 – Comparison of Methods - Sense of Connection to Nature - Average Ratings



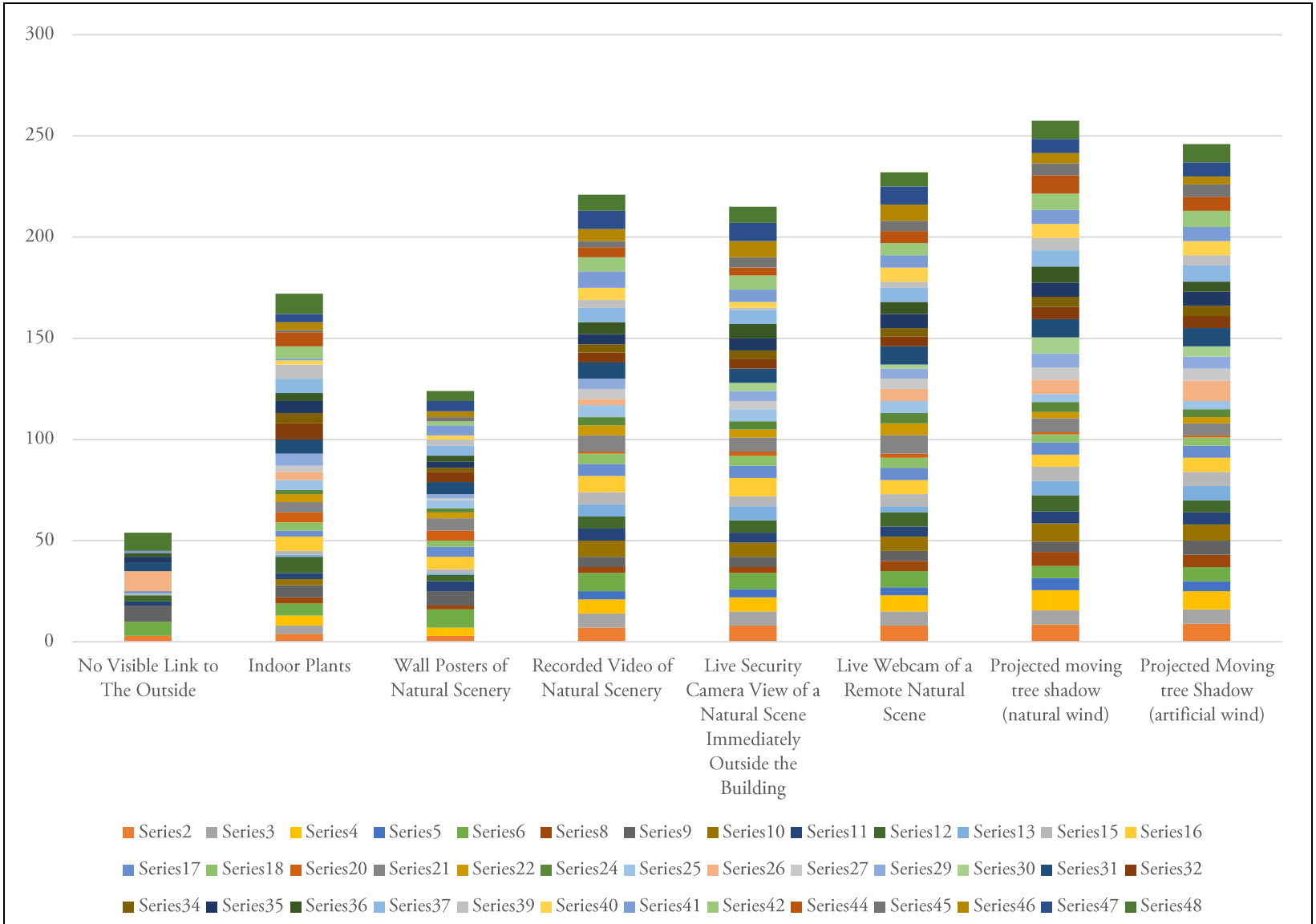
Question 8 – Comparison of Methods - Sense of Connection to Nature - Total Ratings

Question 8 – Comparison of Methods - Amount of Change in the Room								
	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
803-01	3	4	3	7	8	8	8.5	9
803-02	0	4	0	7	7	7	7	7
803-03	0	5	4	7	7	8	10	9
803-04	0	0	0	4	4	4	6	5
803-05	7	6	9	9	8	8	6	7
806-06	0	3	2	3	3	5	7	6
806-07	8	6	7	5	5	5	5	7
806-08	0	3	0	8	7	7	9	8
806-09	2	3	5	6	5	5	6	6
806-10	3	8	3	6	6	7	8	6
806-11	0	1	1	6	7	3	7	7
807-12	1	2	2	6	5	6	7	7
807-13	0	7	6	8	9	7	6	7
807-14	1	3	5	6	6	6	6	6
807-15	0	4	3	5	5	5	4	4
808-16	0	5	5	1	2	2	1	1
808-17	0	5	6	8	7	9	7	6
808-18	0	4	3	5	4	6	3	3
809-19	0	2	2	4	4	5	5	4
809-20	0	5	4	6	6	6	4	4
809-21	10	4	0	3	0	6	7	10

Question 8 – Comparison of Methods - Amount of Change in the Room Continued								
	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
809-22	0	3	1	5	4	5	6	6
813-23	0	6	2	5	5	5	7	6
813-24	0	0	0	0	4	2	8	5
813-25	4	7	6	8	7	9	9	9
813-26	0	8	5	5	5	5	6	6
814-27	0	5	2	4	4	4	5	5
814-28	3	6	3	5	6	7	7	7
814-29	2	4	3	6	7	6	8	5
814-30	0	7	5	7	7	7	8	8
815-31	0	7	3	4	1	3	6	5
815-32	0	2	2	6	3	7	7	7
815-33	1	1	5	8	6	6	7	7
815-34	0	6	2	7	7	6	8	8
816-35	0	7	0	5	4	6	9	7
816-36	0	1	2	3	5	5	6	6
816-37	0	4	3	6	8	8	5	4
816-38	0	4	5	9	9	9	7	7
816-39	9	10	5	8	8	7	9	9
Average	1.384615385	4.41025641	3.179487179	5.666666667	5.512820513	5.948717949	6.602564103	6.307692308



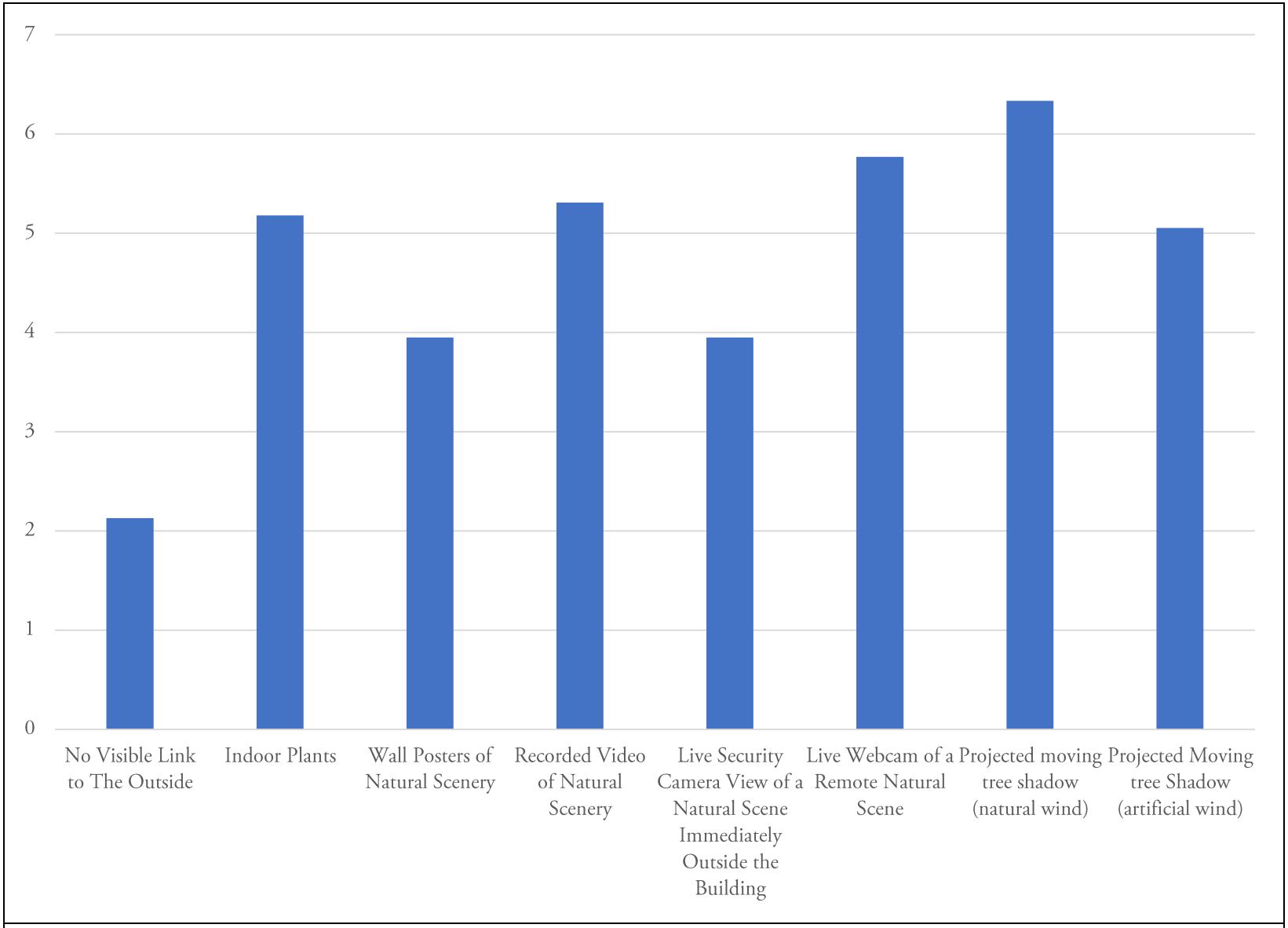
Question 8 – Comparison of Methods - Amount of Change in the Room Average Ratings



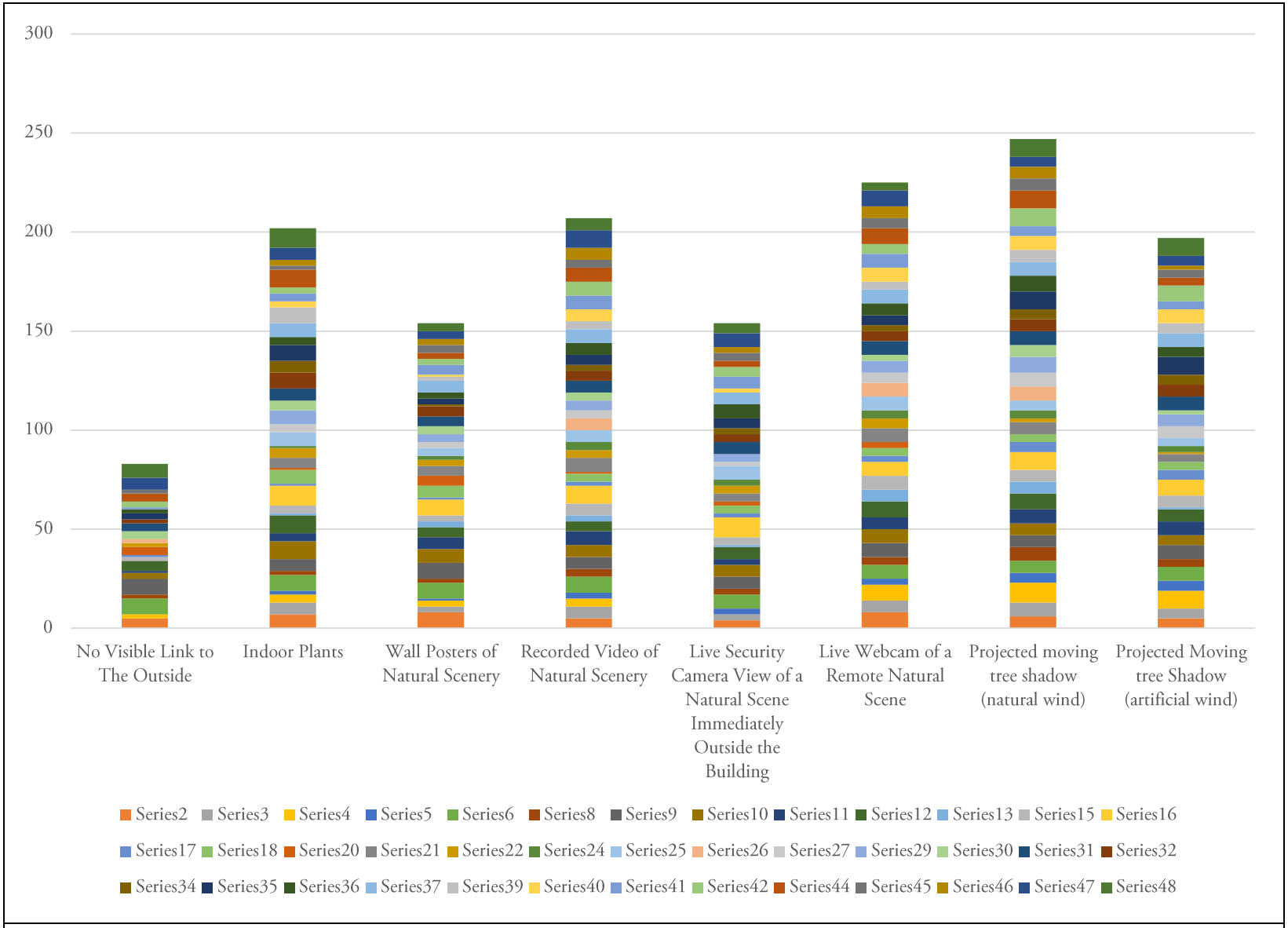
Question 8 – Comparison of Methods - Amount of Change in the Space Total Ratings

Question 8 – Comparison of Methods - Calming Effect								
	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
803-01	5	7	8	5	4	8	6	5
803-02	0	6	3	6	3	6	7	5
803-03	2	4	3	4	0	8	10	9
803-04	0	2	1	3	3	3	5	5
803-05	8	8	8	8	7	7	6	7
806-06	2	2	2	4	3	4	7	4
806-07	8	6	8	6	6	7	6	7
806-08	3	9	7	6	6	7	6	5
806-09	1	4	6	7	3	6	7	7
806-10	5	9	5	5	6	8	8	6
806-11	0	1	3	3	1	6	6	1
807-12	2	4	3	6	4	7	6	6
807-13	0	10	8	9	10	7	9	8
807-14	1	1	1	2	2	3	5	5
807-15	0	7	6	4	4	4	4	4
808-16	4	1	5	1	2	3	0	0
808-17	0	5	5	7	4	7	6	4
808-18	2	5	3	4	4	5	2	1
809-19	0	1	2	4	3	4	4	3
809-20	0	7	4	6	7	7	5	4
809-21	2	0	0	6	0	7	7	0

Question 8 – Comparison of Methods - Calming Effect Continued								
	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
809-22	0	4	3	4	2	5	7	6
813-23	0	7	4	5	4	6	8	6
813-24	4	5	4	4	0	3	6	2
813-25	4	6	5	6	6	7	7	7
813-26	2	8	5	5	4	5	6	6
814-27	0	6	1	3	3	3	5	5
814-28	3	8	3	5	5	5	9	9
814-29	2	4	3	6	7	6	8	5
814-30	0	7	6	7	6	7	7	7
815-31	0	8	2	4	0	4	6	5
815-32	0	3	1	6	2	7	7	7
815-33	1	4	5	7	6	7	5	4
815-34	3	3	3	7	5	5	9	8
816-35	4	9	3	7	3	8	9	4
816-36	2	2	4	4	4	5	6	4
816-37	0	3	3	6	3	6	6	2
816-38	6	6	4	9	7	8	5	5
816-39	7	10	4	6	5	4	9	9
Average	2.128205128	5.179487179	3.948717949	5.307692308	3.948717949	5.769230769	6.333333333	5.051282051



Question 8 – Comparison of Methods - Calming Effect - Average Ratings



Question 8 – Comparison of Methods - Calming Effect - Total Ratings

	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
Connection to the Outside World	0.90	4.90	3.53	4.95	6.08	6.21	5.92	4.67
Connection to Nature	0.64	5.72	3.56	5.40	4.82	6.26	6.10	4.72
Change in Space	1.38	4.41	3.18	5.67	5.51	5.95	6.60	6.31
Calming effect	2.13	5.18	3.95	5.31	3.95	5.77	6.33	5.05
Total	5.05	20.21	14.22	21.32	20.36	24.18	24.96	20.74

Color Key: First | Second | Third

Question 8 – Comparison of Methods – Comparison Matrix

	NO VISIBLE LINK TO THE OUTSIDE	INDOOR PLANTS	WALL POSTERS OF NATURAL SCENERY	RECORDED VIDEO OF NATURAL SCENERY	LIVE SECURITY CAMERA VIEW OF A NATURAL SCENE IMMEDIATELY OUTSIDE THE BUILDING	LIVE WEBCAM OF A REMOTE NATURAL SCENE	PROJECTED MOVING TREE SHADOW (NATURAL WIND)	PROJECTED MOVING TREE SHADOW (ARTIFICIAL WIND)
Connection to the Outside World	0.90	4.90	3.53	4.95	6.08	6.21	5.92	4.67
Connection to Nature	0.64	5.72	3.56	5.40	4.82	6.26	6.10	4.72
Change in Space	1.38	4.41	3.18	5.67	5.51	5.95	6.60	6.31
Calming effect	2.13	5.18	3.95	5.31	3.95	5.77	6.33	5.05
Total	5.05	20.21	14.22	21.32	20.36	24.18	24.96	20.74

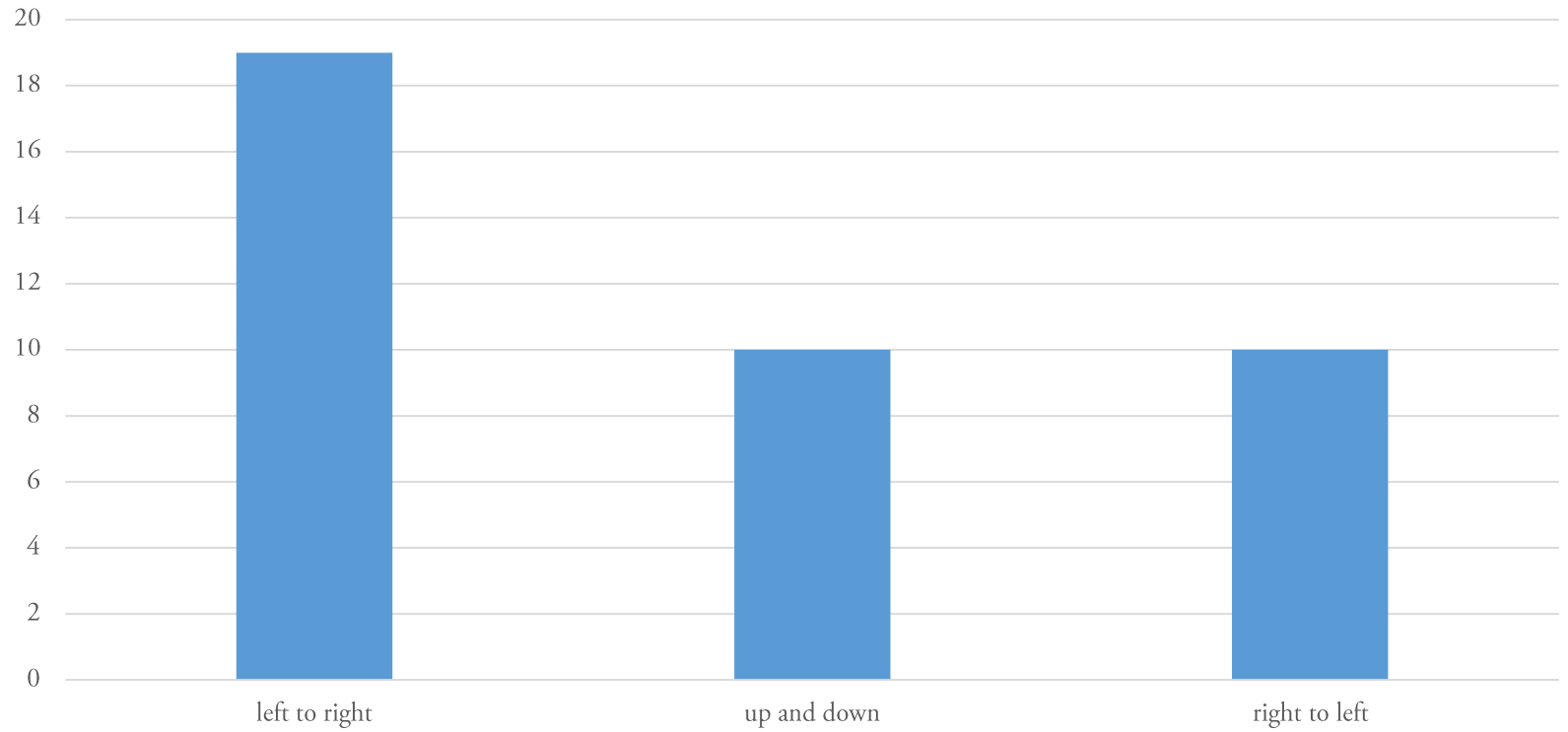
Lowest — Highest

Question 8 – Comparison of Methods – Comparison Matrix Gradient

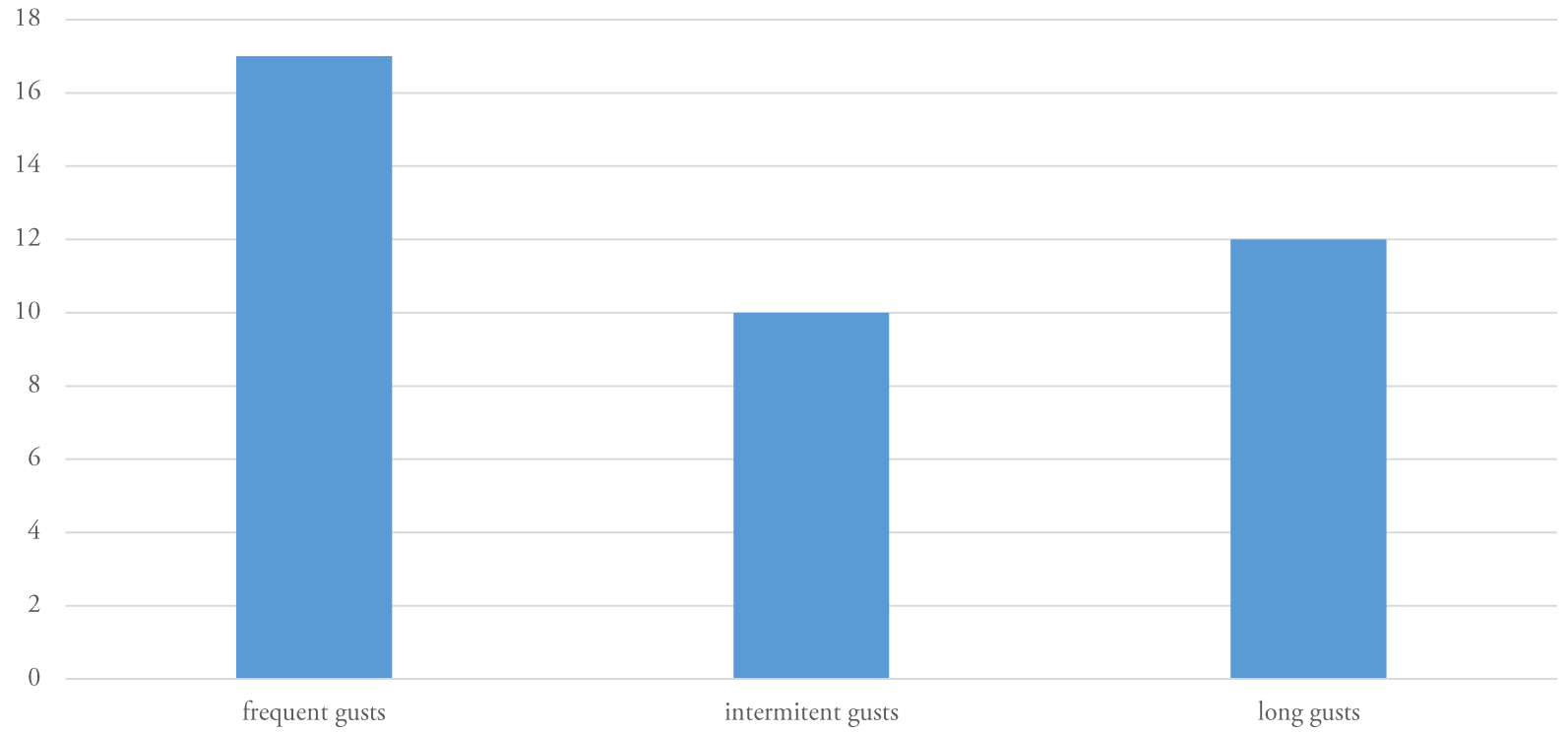
Question 9 - Controllable Shadow Movement User Settings					
	WIND DIRECTION	WIND FREQUENCY	WINDS SPEED	BRANCH STRENGTH	LEAF STRENGTH
803-01	235	9	3	5	0
803-02	7	2	1	0	3
803-03	206	1	2	1	1
803-04	0	0	2	2	0
803-05	7	8	5	2	1
806-06	66	0	2	3	10
806-07	14	1	1	4	8
806-08	353	2	4	3	1
806-09	147	4	0	0	1
806-10	338	0	0	1	0
806-11	147	0	9	1	4
807-12	37	0	3	2	8
807-13	287	5	3	4	2
807-14	360	6	1	4	6
807-15	51	2	1	3	5
808-16	184	0	0	6	0
808-17	169	1	3	2	2
808-18	346	3	0	10	4
809-19	316	6	2	2	0
809-20	8	8	1	3	2
809-21	0	4	3	1	0
809-22	66	7	0	0	10
813-23	0	7	3	0	8
813-24	29	4	3	3	4
813-25	235	5	0	4	4

Question 9 - Controllable Shadow Movement User Settings Continued					
	WIND DIRECTION	WIND FREQUENCY	WINDS SPEED	BRANCH STRENGTH	LEAF STRENGTH
813-26	331	2	2	7	6
814-27	0	8	2	2	8
814-28	353	0	0	7	6
814-29	331	0	1	1	3
814-30	7	7	2	2	5
815-31	198	4	2	2	2
815-32	213	3	4	5	4
815-33	73	8	5	1	1
815-34	206	4	3	2	5
816-35	81	8	2	5	1
816-36	7	9	1	2	7
816-37	37	7	1	5	0
816-38	22	5	8	4	4
816-39	353	9	2	1	2
Average	149.2307692	4.076923077	2.230769231	2.871794872	3.538461538

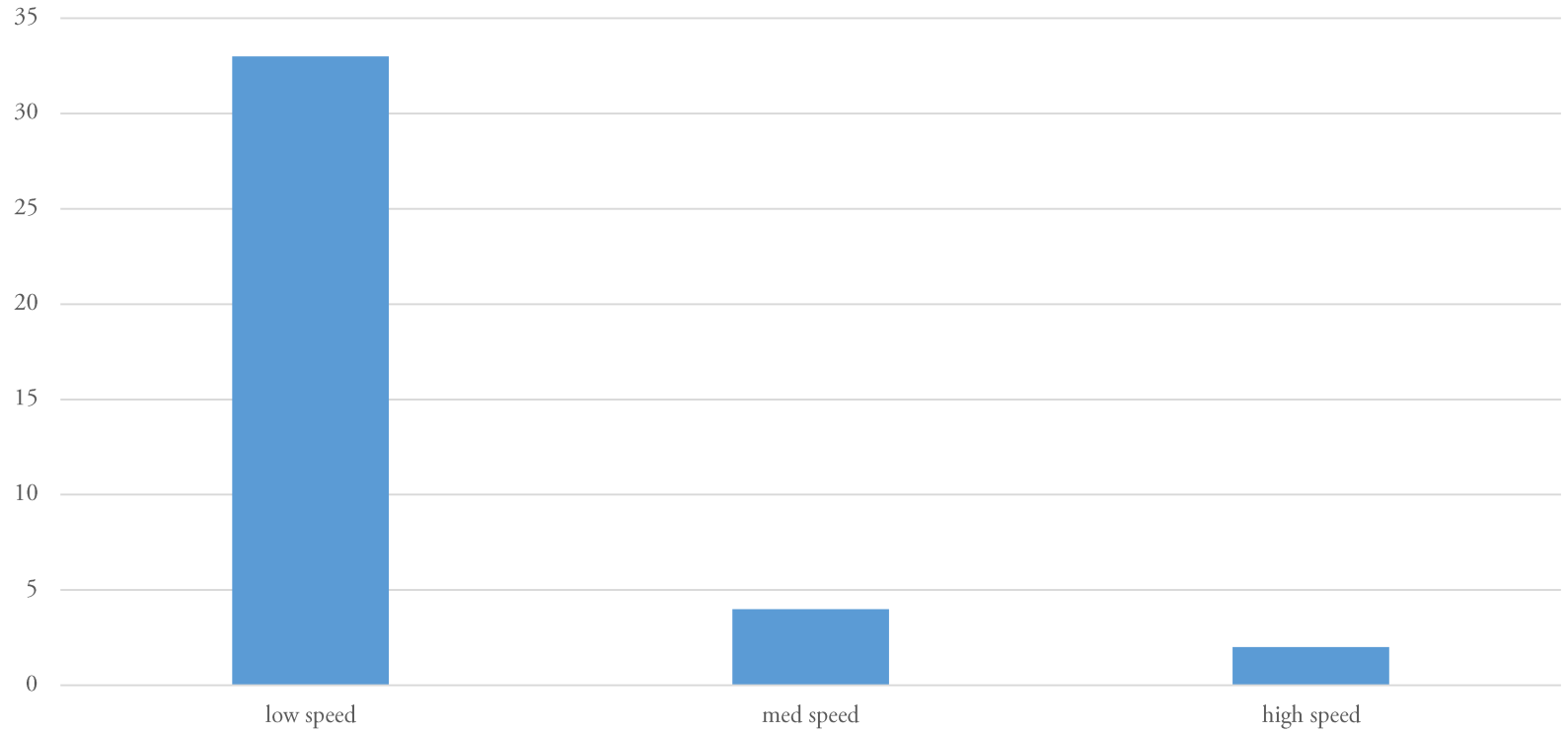
Question 9 - Controllable Shadow Movement User Settings - Wind Direction Settings



Value	*Reaction*	*# of Subjects*
120 deg.	left to right	19
240 deg.	up and down	10
360 deg	right to left	10

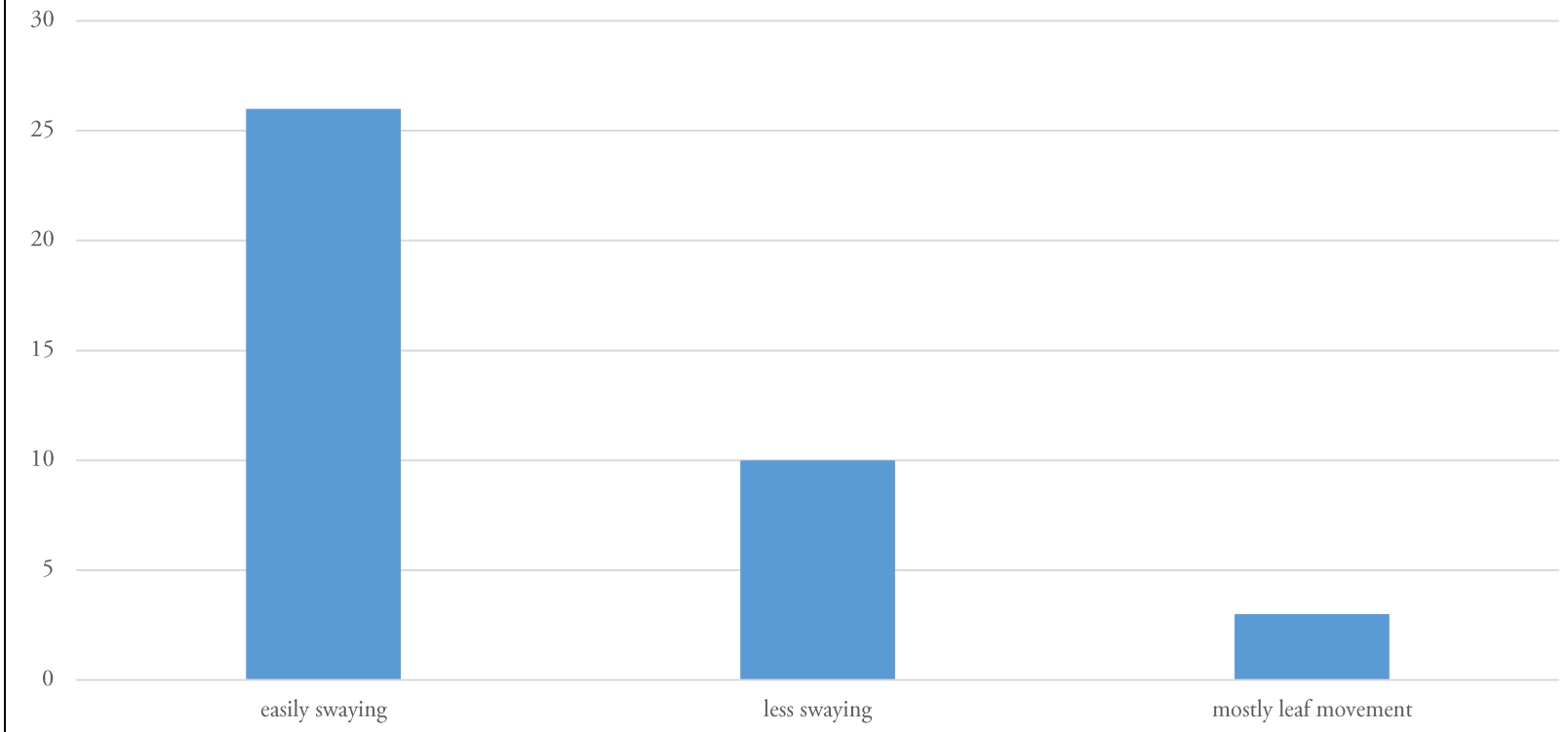
Question 9 - Controllable Shadow Movement User Settings - Wind Gust Frequency Settings		
		
Value	*Reaction*	*# of Subjects*
0 thru 3	frequent gusts	17
4 thru 6	intermittent gusts	10
7 thru 10	long gusts	12

Question 9 - Controllable Shadow Movement User Settings - Wind Speed Settings



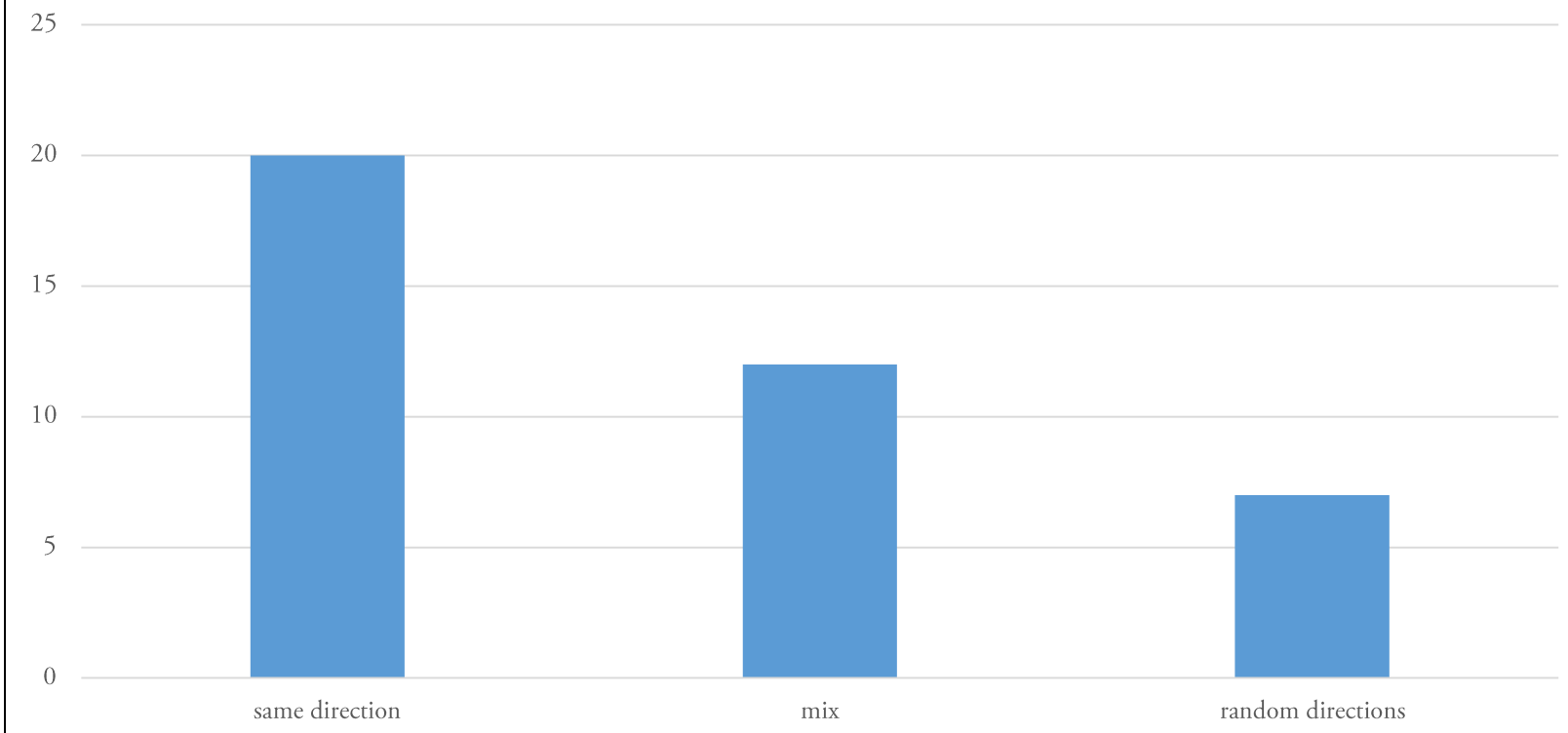
Value	*Reaction*	*# of Subjects*
0 thru 3	low speed	33
4 thru 6	med speed	4
7 thru 10	high speed	2

Question 9 - Controllable Shadow Movement User Settings - Branch Stiffness Settings



Value	*Reaction*	*# of Subject*
0 thru 3	easily swaying	26
4 thru 6	less swaying	10
7 thru 10	mostly leaf movement	3

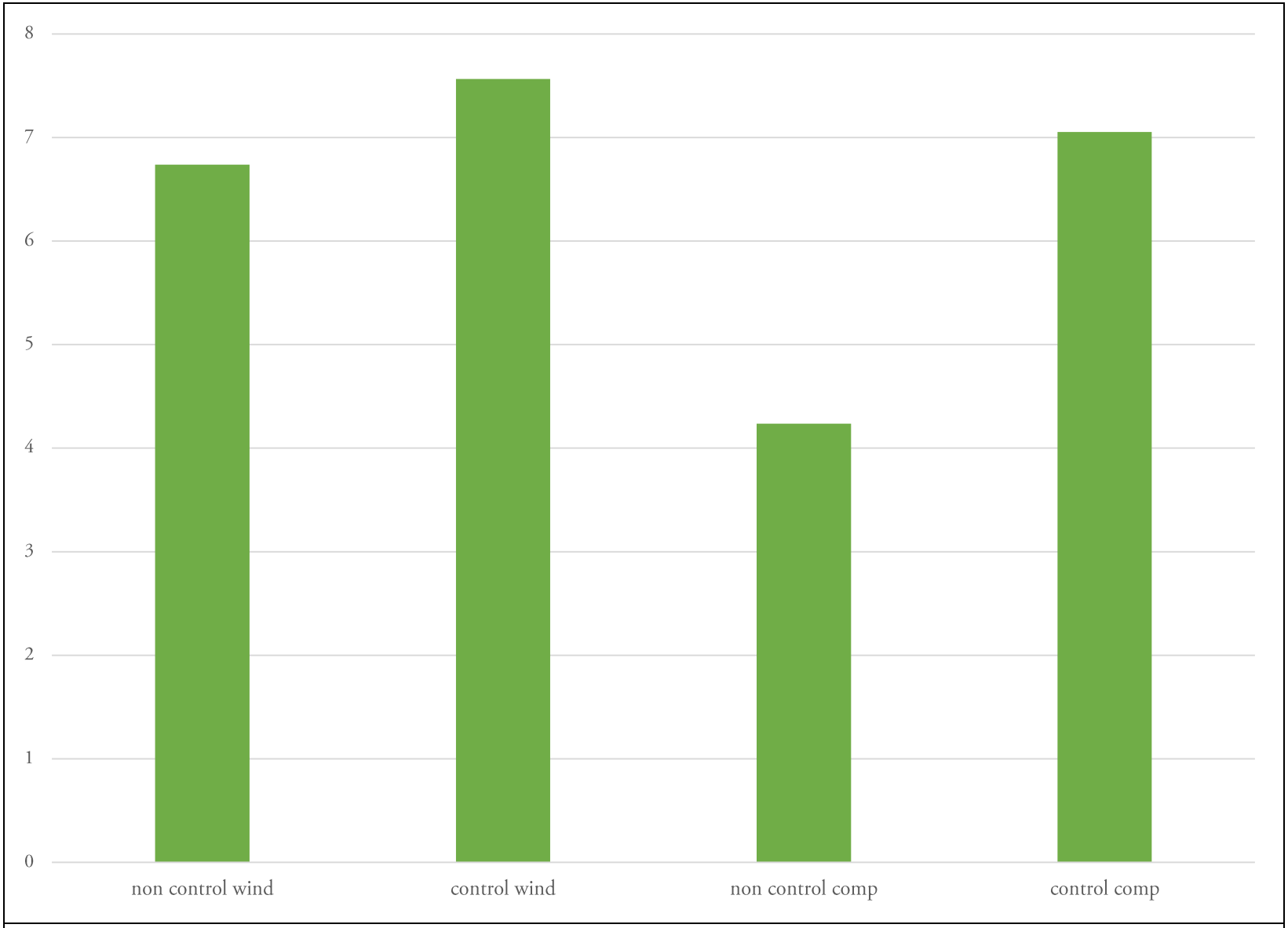
Question 9 - Controllable Shadow Movement User Settings - Leaf Stiffness Settings



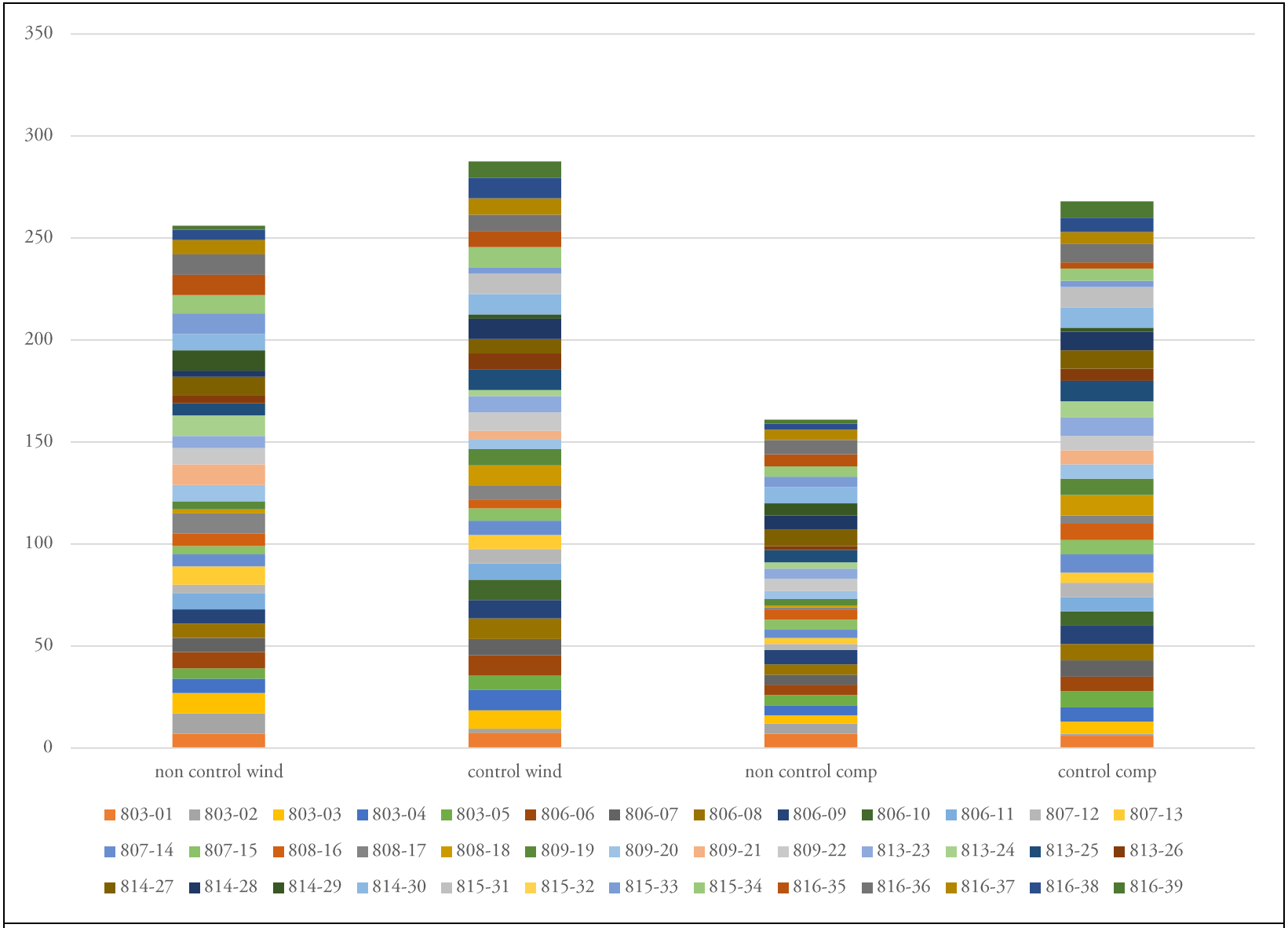
Value	*Reaction*	*# of Subjects*
0 thru 3	same direction	20
4 thru 6	mix	12
7 thru 10	random directions	7

Question 10 - Subject Ratings of Digital-Tree Movement Types				
	NON-CONTROLLABLE WIND-GENERATED MOVEMENT	CONTROLLABLE WIND-GENERATED MOVEMENT	NON-CONTROLLABLE COMPUTER GENERATED MOVEMENT	CONTROLLABLE COMPUTER GENERATED MOVEMENT
803-01	7	7.5	7	6
803-02	10	2	5	1
803-03	10	9	4	6
803-04	7	10	5	7
803-05	5	7	5	8
806-06	8	10	5	7
806-07	7	8	5	8
806-08	7	10	5	8
806-09	7	9	7	9
806-10	0	10	0	7
806-11	8	8	0	7
807-12	4	7	3	7
807-13	9	7	3	5
807-14	6	7	4	9
807-15	4	6	5	7
808-16	6	4	5	8
808-17	10	7	1	4
808-18	2	10	1	10
809-19	4	8	3	8
809-20	8	5	4	7
809-21	10	4	0	7
809-22	8	9	6	7
813-23	6	8	5	9

Question 10 - Subject Rating of Digital-Tree Movement Types Continued				
	NON-CONTROLLABLE WIND-GENERATED MOVEMENT	CONTROLLABLE WIND-GENERATED MOVEMENT	NON-CONTROLLABLE COMPUTER GENERATED MOVEMENT	CONTROLLABLE COMPUTER GENERATED MOVEMENT
813-24	10	3	3	8
813-25	6	10	6	10
813-26	4	8	2	6
814-27	9	7	8	9
814-28	3	10	7	9
814-29	10	2	6	2
814-30	8	10	8	10
815-31	0	10	0	10
815-32	-	-	-	-
815-33	10	3	5	3
815-34	9	10	5	6
816-35	10	8	6	3
816-36	10	8	7	9
816-37	7	8	5	6
816-38	5	10	3	7
816-39	2	8	2	8
Average	6.736842105	7.565789474	4.236842105	7.052631579



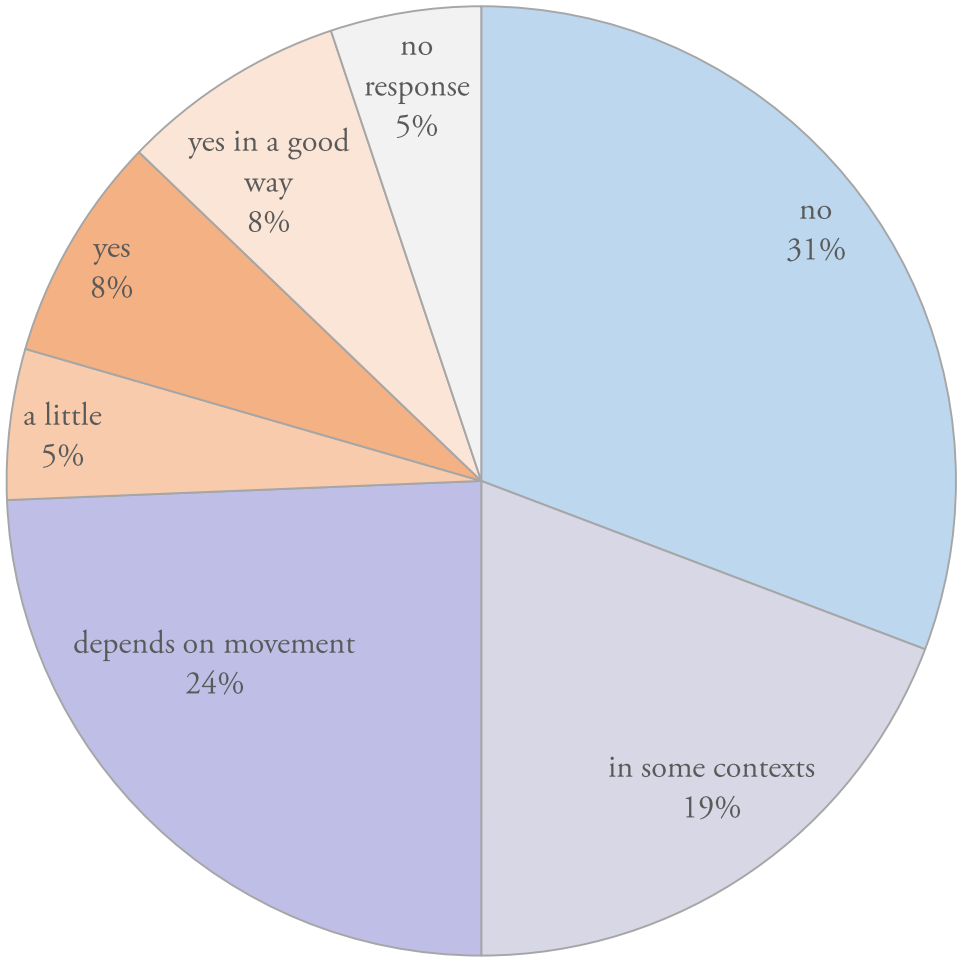
Question 10 - Average Subject Ratings of Digital-Tree Movement Types



Question 10 - Total Subject Rating of Digital-Tree Movement Types

Subjects' Estimates of Likely Distraction (based on comments section)							
	NO	IN SOME CONTEXTS	DEPENDS ON MOVEMENT	A LITTLE	YES	YES IN A GOOD WAY	NO RESPONSE
803-01	1						
803-02	1						
803-03	1						
803-04		1					
803-05	1						
806-06			1				
806-07		1					
806-08						1	
806-09	0.5*	0.5*					
806-10	1						
806-11			1				
807-12						1	
807-13	0.5*	0.5*					
807-14			1				
807-15				1			
808-16					1		
808-17		1					
808-18		1					
809-19			1				
809-20					1		
809-21				1			
809-22			1				
813-23		0.5*	0.5*				
813-24						1	
813-25			1				

Subjects' Estimates of Likely Distraction (based on comments section)							
	NO	IN SOME CONTEXTS	DEPENDS ON MOVEMENT	A LITTLE	YES	YES IN A GOOD WAY	NO RESPONSE
813-26			1				
814-27	1						
814-28	1						
814-29					1		
814-30		1					
815-31		1					
815-32							1
815-33	1						
815-34	1						
816-35							1
816-36	1						
816-37			1				
816-38	1						
816-39			1				
Total	12	7.5	9.5	2	3	3	2
Percent	0.30769231	0.192307692	0.243589744	0.051282	0.076923	0.076923077	0.051282051
*half points indicate split responses							



Subjects' Estimates of Likely Distraction (based on comments section)

APPENDIX C

HEART-RATE DATA

Consolidated Subject Heart-Rate Data							
	BASE	ARTIFICIAL	NATURAL	ARTIFICIAL LABELED NATURAL	NATURAL LABELED ARTIFICIAL	SURVEY	USER CONTROLLED
0:00:00	68.26184	71.67632	74.33041			74.99211	68.24013
	68.21053	71.62632	71.75			74.91579	68.17763
	68.11053	71.75526	69.13889			74.88553	68.16776
	70.11184	71.78158	69.10965			74.88553	67.91612
	69.93026	69.20658	68.92251			74.78026	67.74836
	71.21447	69.05263	68.70906			74.68158	67.58059
	73.10921	71.52895	68.52339			74.70263	67.41283
	70.63553	69.975	68.39035			74.60132	69.49013
	70.52763	69.92237	68.0614			74.40395	69.5477
0:00:10	72.89079	69.84474	69.8962	69.860526	73.109211	74.52763	69.5
	72.73684	69.71316	70.12281	69.959211	73.157895	74.75658	69.60526
	72.57763	69.45132	70.06579	70.059211	71.281579	70.37895	69.69901
	72.52237	70.66711	69.93421	69.982895	71.460526	71.13947	69.83553
	72.59474	70.40263	72.27047	69.156579	71.435526	69.21711	69.62993
	72.78684	72.24474	72.24123	69.006579	71.436842	69.26579	69.63487
	72.78421	72.13947	72.19006	68.963158	71.231579	68.05789	69.52961
	72.60658	72.11053	72.10819	68.738158	71.152632	67.95658	69.53454
	72.60921	72.05395	70.16667	68.692105	72.289474	67.825	69.55592
	72.48158	71.975	71.70468	71.234211	72.061842	69.79211	67.49836
0:00:20	70.64342	71.99868	71.76462	71.230263	71.725	69.71579	69.74342
	70.71842	72.02105	71.70906	71.206579	71.543421	71.61711	69.88487
	70.46579	71.98947	71.7076	71.157895	71.538158	71.59605	70.10362
	70.33816	71.98684	69.42251	71.081579	71.352632	71.67237	70.15625
	70.26184	72.01184	69.42398	70.775	71.223684	71.80132	70.125
	70.18947	71.90526	69.42251	70.697368	70.894737	71.67632	70.1875

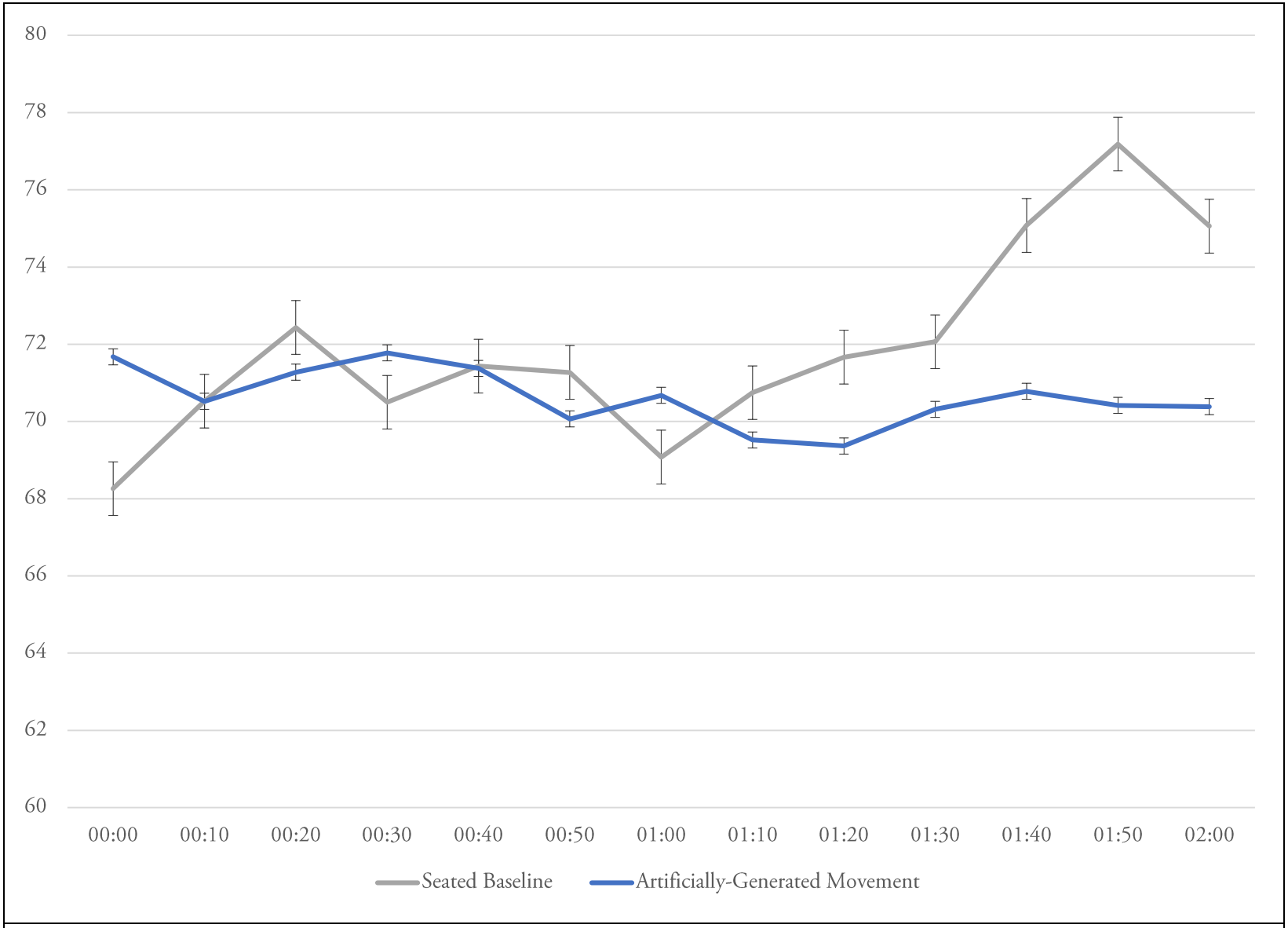
Consolidated Subject Heart-Rate Data Continued							
	BASE	ARTIFICIAL	NATURAL	ARTIFICIAL LABELED NATURAL	NATURAL LABELED ARTIFICIAL	SURVEY	USER CONTROLLED
	69.85789	71.80395	69.34649	73.072368	72.586842	71.85658	70.2352
	69.58289	71.70132	69.29532	73.148684	72.356579	73.86053	70.15132
	71.22237	71.52237	69.32895	73.052632	72.175	71.88289	70.09375
	71.14737	71.49474	69.41228	72.959211	72.047368	71.78026	70.27796
0:00:30	71.20526	71.31579	69.47076	72.760526	71.921053	71.80789	70.33553
	71.23553	71.44211	69.55117	72.657895	71.631579	73.48289	70.56579
	71.18684	71.43816	69.65789	72.528947	71.526316	73.30658	70.61349
	71.36579	71.53816	69.66082	72.626316	71.578947	73.30921	70.875
	71.41447	71.56316	72.05994	72.415789	71.526316	71.03684	71.12171
	71.54079	71.50921	72.03509	72.264474	71.5	71.00921	71.26809
	71.54211	71.50921	71.98392	72.185526	71.315789	70.90789	71.35197
	71.53816	71.37895	72.04094	72.128947	68.973684	70.83421	71.35197
	71.54211	71.275	72.01901	72.002632	68.921053	70.85789	71.35691
	71.46447	71.09868	71.99561	71.925	68.973684	70.60132	71.30428
0:00:40	71.51711	70.99737	69.8655	71.826316	68.894737	70.52105	71.12171
	71.625	70.87368	69.86842	71.826316	68.684211	72.66711	71.24671
	71.46842	70.95132	69.89766	71.826316	68.5	70.46316	71.27303
	71.47105	71.03289	69.9269	71.742105	70.421053	70.45921	71.26809
	71.44605	71.03684	69.84649	71.790789	70.368421	66.88026	71.25822
	71.31842	69.37632	69.74269	71.711842	70.605263	64.90526	71.28947
	71.26447	69.45263	69.71491	71.425	70.763158	65.00789	71.27303
	71.15921	69.32632	69.58333	71.321053	70.868421	64.88026	71.00658
	71.05132	69.40395	69.42398	71.193421	70.973684	64.85658	70.82401
	70.94474	69.58289	69.42251	71.114474	69.131579	64.70132	70.74507
0:00:50	70.94211	69.63289	67.60819	70.985526	71	64.75132	70.69737

Consolidated Subject Heart-Rate Data Continued							
	BASE	ARTIFICIAL	NATURAL	ARTIFICIAL LABELED NATURAL	NATURAL LABELED ARTIFICIAL	SURVEY	USER CONTROLLED
	69.17632	69.63158	67.58187	70.936842	71	62.31184	70.47204
	69.14737	69.60658	67.60526	71.014474	70.842105	62.26316	70.33059
	69.02237	69.48158	69.39474	69.585526	70.763158	62.33947	70.38816
	68.87105	69.53289	71.63158	69.659211	70.815789	64.07763	70.44079
	68.9	71.44868	71.63012	69.530263	70.868421	66.10658	70.45066
	69.175	71.425	71.54678	69.659211	70.789474	66.00263	70.50822
	69.20556	71.50263	71.3845	69.709211	71	67.89737	70.73355
	69.23611	71.42895	71.43713	71.184211	71.131579	67.97895	69.3125
	69.08056	71.35395	71.59942	69.885526	71.131579	70.13289	69.36513
0:01:00	68.95278	71.35526	71.75877	69.836842	71.236842	70.16053	69.4227
	68.95833	69.80789	71.80848	69.892105	71.131579	70.16053	69.4227
	70.74444	69.73553	71.88596	69.919737	71.157895	71.24605	69.61184
	70.75	69.63684	72.1769	69.919737	70.973684	73.50789	69.61678
	70.73056	69.63553	72.2807	71.296053	70.894737	73.35526	69.42763
	70.73333	69.45789	72.44152	71.369737	68.473684	73.37895	70.91118
	70.84167	69.38026	72.54971	71.369737	68.5	73.275	70.8898
	71.08889	69.38026	70.88596	71.319737	68.526316	73.27632	70.90625
	71.13611	69.40526	70.91667	71.319737	68.631579	73.25395	71.35439
	71.08333	69.37632	70.94298	71.192105	68.815789	73.51053	71.31404
0:01:10	71.40278	69.40263	70.86404	71.065789	68.921053	73.53421	71.42632
	71.38596	69.45263	70.62384	71.114474	68.921053	73.46184	71.34737
	71.40936	69.4	70.59752	71.323684	67.657895	73.43421	71.35439
	71.62281	69.39868	70.54799	71.373684	67.736842	73.53684	69.22281
	71.61988	69.44868	72.14706	71.347368	70.105263	73.53816	69.18947
	71.7807	69.44474	72.09133	71.351316	70.026316	73.53947	71.43333

Consolidated Subject Heart-Rate Data Continued							
	BASE	ARTIFICIAL	NATURAL	ARTIFICIAL LABELED NATURAL	NATURAL LABELED ARTIFICIAL	SURVEY	USER CONTROLLED
	71.78793	69.36974	72	71.144737	70.078947	73.56316	71.49298
	71.94582	69.36974	71.99381	71.246053	70.052632	73.56316	71.5193
	72.02167	69.34474	72.04025	71.323684	70.052632	73.23684	71.5193
	71.53922	69.21974	72.03096	71.222368	70.105263	73.26316	71.47193
0:01:20	71.56209	69.22237	72.16873	71.222368	70.078947	73.28947	71.58421
	71.58824	69.14474	72.28019	71.172368	70.105263	73.31579	71.32456
	71.66993	69.16842	70.3096	71.015789	68.131579	71.26316	71.36491
	71.69444	70.53684	70.3065	71.040789	68.157895	71.26316	71.47719
	71.5	70.51316	72.19814	70.938158	68.342105	71.28947	71.58947
	71.58824	70.45921	72.17492	70.888158	68.394737	71.26316	71.70175
	71.73529	70.51184	72.06656	70.967105	68.447368	71.21053	71.77368
	70.63333	70.58684	70.09288	71.068421	68.342105	71.18421	71.8807
	73.46923	70.76053	70.12229	71.171053	68.342105	69.92105	71.70877
	73.725	70.70395	70.09288	71.119737	68.342105	71.31579	71.59649
0:01:30	73.05	70.77895	70.17492	71.148684	69.657895	71.31579	71.39123
	72.76389	70.82632	70.25387	71.2	69.736842	71.31579	71.29123
	73.16667	70.85	70.3096	71.101316	69.657895	71.34211	70.65
	73.05556	70.94737	72.38854	69.523684	69.605263	71.65789	70.78333
	73.24306	70.97237	72.28328	69.473684	69.605263	71.78947	70.96275
	73.67857	70.99737	72.1548	69.475	69.605263	71.84211	70.96667
	73.40179	70.92368	72.09907	69.423684	71.684211	71.89474	71.1
	75.64286	70.95132	72.02012	69.344737	71.631579	71.94737	71.16667
	78.83333	70.97895	72.02632	67.873684	71.736842	70.05263	70.98824
	79.4	71.03026	72.0356	67.848684	71.684211	70.34211	70.98431
0:01:40	77.6	69.33289	72.0356	67.451316	71.605263	72.10526	70.9549

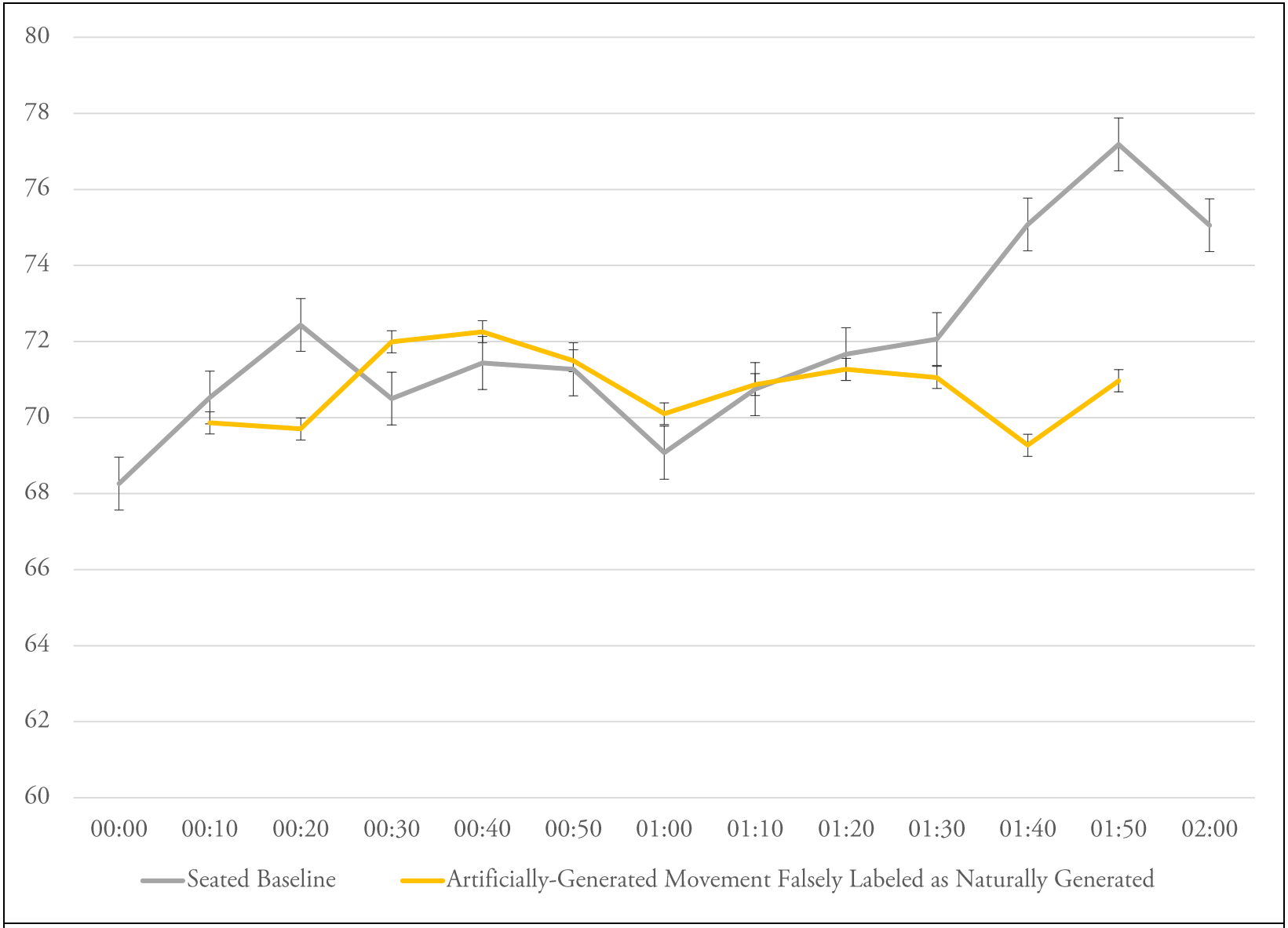
Consolidated Subject Heart Rate Data Continued							
	BASE	ARTIFICIAL	NATURAL	ARTIFICIAL LABELED NATURAL	NATURAL LABELED ARTIFICIAL	SURVEY	USER CONTROLLED
	77.8	69.33684	72.0625	67.677632	71.552632	68.65789	70.8
	77.8	70.61389	72.28783	67.708333	71.633041	68.68421	70.76275
	76.75	70.62222	72.45559	71.158824	71.333333	68.65789	70.72549
	76.5	70.625	72.42434	71.238235	70.732026	72.13158	70.7549
	76.625	70.60278	72.41447	70.728758	70.759804	71.48538	70.88039
	76.75	70.52778	72.52467	71.534722	70.728758	71.43129	70.88431
	77.125	70.42222	72.52961	71.858824	70.647059	73.24854	70.94706
	78.08333	70.48056	71.97917	73.375	70.962745	71.90936	70.88431
	77.33333	70.475	71.5	73.434524	71.02549	71.9883	70.97647
0:01:50	77.08333	70.46667	71.4			71.95468	70.9098
	76.33333	70.35833	71.1627			71.95614	70.77647
	76	70.74853	71.23016			72.03655	70.80588
	73	70.84853	71.24603			72.09064	70.89804
	72.25	70.86912	71.2381			72.11257	65.95294
	71.5	70.97353	71.55952			72.27193	68.51961
	71.25	70.39938	71.55159			72.24561	68.40588
	70.75	70.62908	71.62302			72.21784	70.52353
	77	70.23529	71.53175			72.05117	70.36471
	76.5	69.6636	71.56746			72.02485	70.26863
0:02:00	86	69.13333	71.03151			72.02193	70.29804
Averages	72.16318	70.54968	70.95963	70.885899	70.467512	71.09565	70.40706

Average Consolidated Subject Heart Rate Data at 10 Second Intervals							
	BASE	ARTIFICIAL	NATURAL	ARTIFICIAL LABELED NATURAL	NATURAL LABELED ARTIFICIAL	SURVEY	USER CONTROLLED
0:00:00	68.26184	71.67632	74.33041	*	*	74.99211	68.24013
0:00:10	70.52675	70.52149	69.16683	69.860526	73.109211	74.70936	68.39346
0:00:20	72.43434	71.27566	71.25687	69.702237	71.723289	69.81053	69.42664
0:00:30	70.49895	71.77526	69.85395	71.991184	71.763947	71.95513	70.1551
0:00:40	71.43474	71.375	71.08699	72.256184	70.484211	71.58671	71.09309
0:00:50	71.26908	70.06697	69.50351	71.493684	70.131579	66.95724	71.08816
0:01:00	69.07671	70.67671	70.55702	70.100132	70.957895	65.92711	70.14243
0:01:10	70.74694	69.52184	71.67529	70.866447	69.602632	72.84987	70.48809
0:01:20	71.66754	69.36711	71.62415	71.266974	69.481579	73.44263	71.01351
0:01:30	72.06537	70.31645	70.98189	71.053026	68.626316	71.33421	71.58088
0:01:40	75.07857	70.78105	71.76068	69.271579	70.655263	71.42895	70.98481
0:01:50	77.185	70.4173	72.15782	70.968317	71.041654	71.01491	70.85255
0:02:00	75.05833	70.38587	71.37418	*	*	72.10292	69.68137
Average	72.16318	70.54968	70.95963	70.885899	70.467512	71.09565	70.40706
* The same videos were shown without the initial and final 5 seconds							

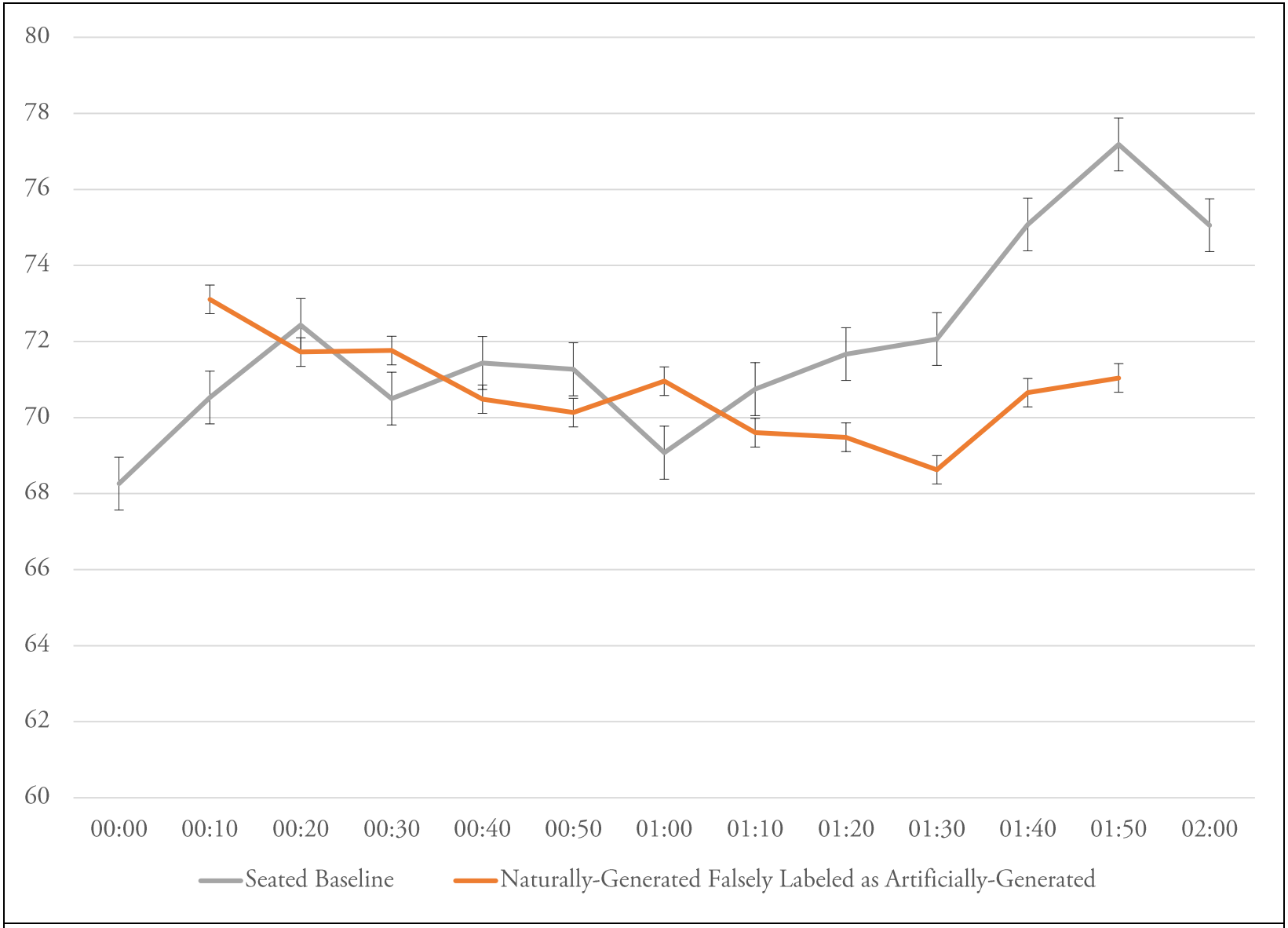


Average Heart Rate at 10 Second Intervals: Artificially-Generated Movement

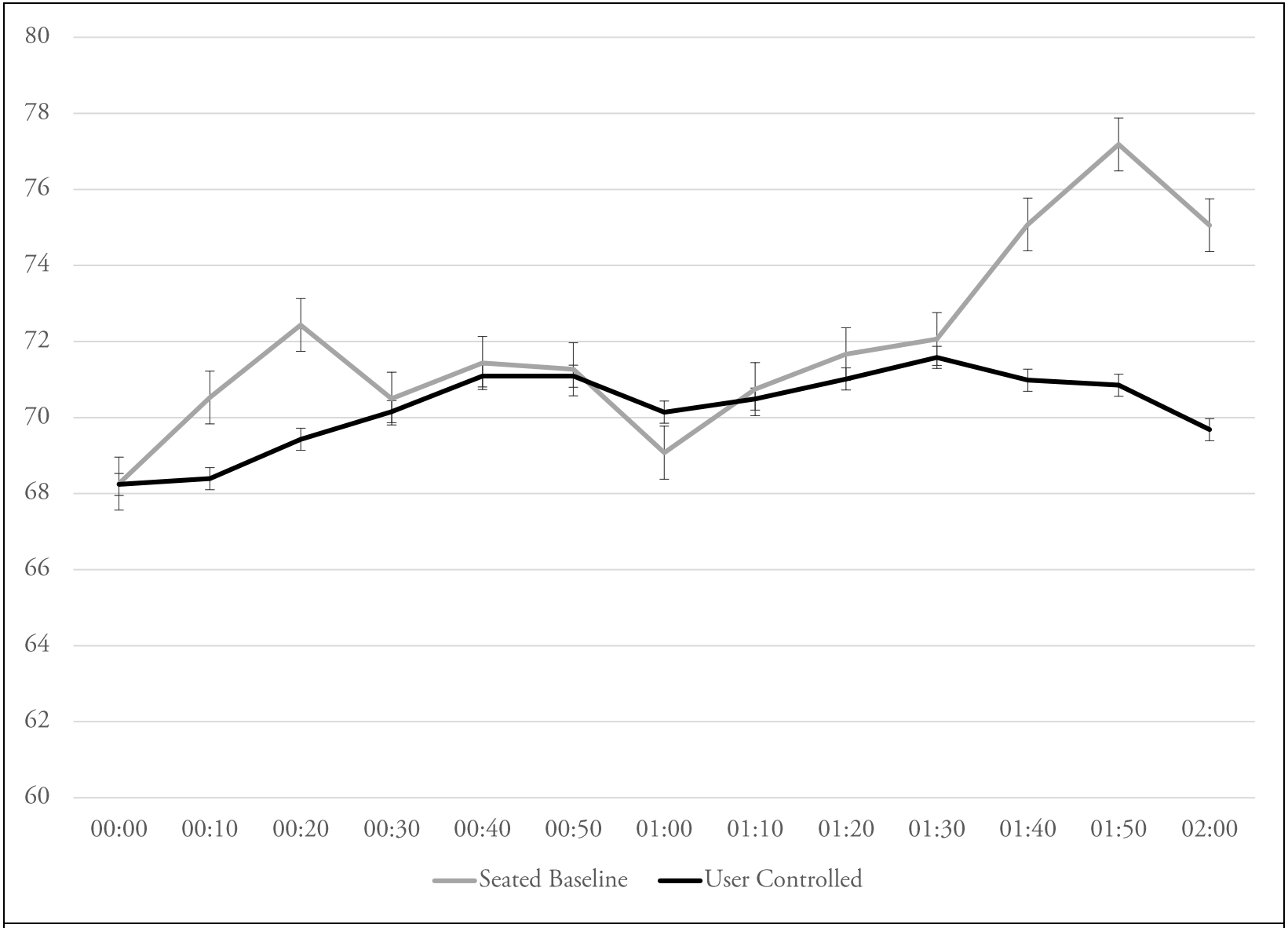
Average Heart Rate At 10 Second Intervals: Naturally-Generated Movement



Average Heart Rate at 10 Second Intervals: Artificially-Generated Movement Falsely Labeled Natural



Average Heart Rate at 10 Second Intervals: Naturally-Generated Movement Falsely Labeled Artificial



Average Heart Rate at 10 Second Intervals: Subject-Controlled Movement

APPENDIX D

DIGITAL-TREE SHADOW CODE

Processing Setup Code

```
import fullscreen.*;
FullScreen fs;
void Full() {
  // Create the fullscreen object
  fs = new FullScreen(this);
  // enter fullscreen mode
  fs.enter();
}
int width = 640;
int height = 480;
float transparency = 150;
color leafColor = color (100, 100, 100, 240);
color branchColor = color(100, 100, 100);
color skyColor = color(255, 255, 255);
//branch controls
int treeNumber = 2;
int nSegments;
float totalBranchLength;
float maxBranchThickness;
float minBranchThickness;
float minSpawnDistance; //this controls how far
the branch will grow before splitting
float branchSpawnOdds;   //the odds of a branch
growing there
float branchSpawnOddsOfSecond; //odds of a
second branch growing from the same node
float mindThetaSplit;
float maxdThetaSplit;
float maxdThetaWander;
float dBranchSize; //the new branch may change
by 1.0+/- this amount
//leaf controls
float minLength; //leaf length
float maxLength; //leaf length
float minWidth;  //leaf width as a factor of length
float maxWidth;  //leaf width as a factor of length
float maxBranchSizeForLeaves;
float leafSpawnOdds;
branch[] branches;
boolean pauseWind = false;
boolean drawWind = false;
boolean drawLeaves = true;
void setup() {
 //only for live wind
// liveWind();
 // liveDirection();
//  liveVelocity();
  size(width, height);
  frameRate(30);
  smooth();
  noStroke();
  //Full();
//serialSetup(); for live or control
// only for control
//font = loadFont("AgencyFB-Reg-48.vlw");
  initializeTreeValues();
  windDirection = 0;
  windVelocity = 0;
  defineLeafOutline();
  generateBranches();
  redrawTrees();
}
void draw() {
  if (!pauseWind) {
    updateWind();
    //move in the wind!
    for (int i = 0; i<treeNumber; i++)
      branches[i].rotateDueToWind();
       //textdraw(); for knob readout only
    redrawTrees();
    //draw the wind line
    if (drawWind)
      drawWindLine();
  }
}
void redrawTrees() {
  background(skyColor);
  drawBranches();
  if (drawLeaves)
    drawLeaves();
}
void drawBranches() {
  stroke(branchColor);
  for (int i = 0; i<treeNumber; i++)
  branches[i].drawBranch(new float[] {
    //(1+i)*((width/(1+treeNumber)*1.5)),
height+(height/90) //multiple trees
    //(1+i)+(width/3), height+(height*.1) // one
dense tree large screen
    (1+i)+(width/2), height + (height/32) // one
dense tree 640
   // (1+i)+(width/3), height+(height/2.5) // one
dense tree small screen
  }
```

Processing Setup Code Continued

```
}
void drawLeaves() {
  noStroke();
  fill(leafColor);
  //draw leaves
  for (int i = 0; i<treeNumber; i++)
  branches[i].drawLeaves(new float[] {
    (1+i)*(width/(1+treeNumber)), height
  }
  );
}
void drawWindLine() {
  stroke(0);
  int dx= 100;
  int dy = 100;
  line(dx, dy,
dx+50*windVelocity*cos(windDirection),
dy+50*windVelocity*sin(windDirection));
  noStroke();
  fill(0);
  ellipse(dx, dy, 3, 3);
}
void initializeTreeValues() {
  pauseWind = false;
  drawWind = false;
  drawLeaves = true;
  //branch
  nSegments = 20;
  totalBranchLength = 500;
  maxBranchThickness = 9;
  maxBranchSizeForLeaves = 5;
  minBranchThickness = 2;
  minSpawnDistance = .1;
  branchSpawnOdds = .3;
  branchSpawnOddsOfSecond = 0;
  mindThetaSplit = 0;
  maxdThetaSplit = PI/5;
  maxdThetaWander = PI/5;
  dBranchSize = .2;
  //leaves
  minLength = 3;
  maxLength = 20;
  minWidth = .4;
  maxWidth = .5;
  leafSpawnOdds = 1.0;
  transparency = 240;//100;
  generateBranches();
}
void mouseClicked() {
  generateBranches();
  windDirection = random(TWO_PI);
  redrawTrees();
}
void keyTyped() {
  if (key == 'm') {
    drawWind = !drawWind;
    println(drawWind);
  }
   if (key=='l')
    drawLeaves = !drawLeaves;
  if (key == 'p') {
    pauseWind = !pauseWind;
    if (pauseWind)
      windVelocity = 0;
  }
  if (key == '=') {
    if (transparency<240) {
      transparency +=10;
      leafColor = color(100, 100, 100,
transparency);
      color(5, 113, 3, transparency);
    }
    println("transparency: "+transparency);
  }
  if (key == '-') {
    if (transparency>0) {
      transparency -=10;
      leafColor = color(100, 100, 100,
transparency);//color(5,113,3,transparency);
    }
    println("transparency: "+transparency);
  }
    redrawTrees();
}
```

Branch Code

```
void generateBranches() {
  branches = new branch[treeNumber];
  for (int i = 0; i<treeNumber; i++)
    branches[i] = new branch(-1, 3*PI/2,
totalBranchLength, maxBranchThickness);
}
class branch {
  float x, y, theta, startingThickness;
  float theta0;
  float[] thetas;
  int index = -1; //this tells what segment the
branch has spawned at.
  // if it's -1, it's the root.
  float segmentLength;
  ArrayList myChildren;
  ArrayList myLeaves;
  //this one's to generate a parent branch!
  branch(int index0, float thetaI, float totalLength,
  float startingThickness0) {
    index = index0;
    myChildren = new ArrayList();
    myLeaves = new ArrayList();
    segmentLength = totalLength/nSegments;
    startingThickness = startingThickness0;
    theta0 = thetaI;
    thetas = new float[nSegments]; //r,theta
    thetas[0] = theta0;
    for (int i=1; i<nSegments; i++) {
      thetas[i] = thetas[i-1]+random(-
maxdThetaWander, maxdThetaWander);
    }
    //this'll spawn the baby branches!
    for (int i=1; i<nSegments; i++) {
      if (startingThickness*(1-(float)i/nSegments)>
minBranchThickness &&
        (float)i/nSegments > minSpawnDistance &&
        random(1) <= branchSpawnOdds) {//add a
baby!
        float dThetaSign = randomSign();
        myChildren.add(new branch(i,
thetas[i]+dThetaSign*random(mindThetaSplit,
maxdThetaSplit),
        totalLength*(1-
(float)i/nSegments)*random(1-dBranchSize,
1+dBranchSize),
        //
totalLength*random(.3,.6),
        startingThickness*(1-(float)i/nSegments)));
        if
(random(1)<=branchSpawnOddsOfSecond)
          myChildren.add(new branch(i, thetas[i]-
dThetaSign*random(mindThetaSplit,
maxdThetaSplit),
          totalLength*(1-
(float)i/nSegments)*random(1-dBranchSize,
1+dBranchSize),
          //
totalLength*random(.3,.6),
          startingThickness*(1-(float)i/nSegments)));
      }
    }
    //this'll add leaves!
    for (int i=1; i<nSegments; i++) {
      if (startingThickness*(1-(float)i/nSegments)<
maxBranchSizeForLeaves &&
        random(1)<leafSpawnOdds)
        myLeaves.add(new leaf(thetas[i], i));
    }
  }
  //gives the location of the nth node
  float[] getCoordsOf(int n) {
    float x2 = x;
    float y2 = y;
    for (int i=0; i<n; i++) {
      x2 += segmentLength*cos(thetas[i]);
      y2 += segmentLength*sin(thetas[i]);
    }
    return new float[] {
      x2, y2
    };
  }
  void rotate(float dTheta) {
    //rotate myself
    for (int i=0; i<nSegments; i++)
      thetas[i]+=dTheta;
    //rotate my leaves
    for (int i=0; i<myLeaves.size(); i++)
      ((leaf)myLeaves.get(i)).rotate(dTheta);
    //rotate my children
    for (int i=0; i<myChildren.size(); i++)
      ((branch)myChildren.get(i)).rotate(dTheta);
  }
  void rotateDueToWind() {
    float dThetaWind = (thetas[0]-windDirection);
    float dThetaBranch = (thetas[0]-theta0);
    if (dThetaWind>PI)
```

Branch Code Continued

```
    dThetaWind = -(TWO_PI-dThetaWind);
   else if (dThetaWind<-PI)
    dThetaWind = TWO_PI+dThetaWind;

   if (dThetaBranch>PI)
    dThetaBranch = -(TWO_PI-dThetaBranch);
   else if (dThetaBranch<-PI)
    dThetaBranch = TWO_PI+dThetaBranch;
   float forceOfBranch = -(thetas[0]-
theta0)*((startingThickness/(maxBranchThickness
))*1.1);
   float forceOfWind = -
windVelocity*sin(dThetaWind)/10;
   float moveAmount = noise(random(16,
24))*50;
     //this moves the branch
   rotate((forceOfBranch+forceOfWind)/
moveAmount );//20);
   //this moves the leaves!
   for (int i=0; i<myLeaves.size(); i++)
    ((leaf)myLeaves.get(i)).moveFromWind();
   //this'll rotate the children
   for (int i=0; i<myChildren.size(); i++)

((branch)myChildren.get(i)).rotateDueToWind();
  }
  void drawBranch(float[] coords) {
   x = coords[0];
   y = coords[1];
   float x1 = x;
   float y1 = y;
   float x2, y2;
   for (int i=0; i<nSegments; i++) {
    x2 = x1+segmentLength*cos(thetas[i]);
    y2 = y1+segmentLength*sin(thetas[i]);
    strokeWeight(startingThickness*(1-
(float)i/nSegments));
    line(x1, y1, x2, y2);
    x1 = x2;
    y1 = y2;
   }
   //draw children
   for (int i=0; i<myChildren.size(); i++)

((branch)myChildren.get(i)).drawBranch(getCoor
dsOf(((branch)myChildren.get(i)).index));
  }
  void drawLeaves(float[] coords) {
   for (int i=0; i<myLeaves.size(); i++)

((leaf)myLeaves.get(i)).draw(getCoordsOf(((leaf)
myLeaves.get(i)).index));
   //draw children's leaves
   for (int i=0; i<myChildren.size(); i++)

((branch)myChildren.get(i)).drawLeaves(coords);
  }
}
int randomSign() { //returns +1 or -1
  float num = random(-1, 1);
  if (num==0)
   return -1;
  else
   return (int)(num/abs(num));
}
```

Leave Code: Graphics

```
int nLeafPoints = 12;
float[] xOutline;
float[] yOutline;
void defineLeafOutline() {
  xOutline = new float[nLeafPoints];
  yOutline = new float[nLeafPoints];
  for (int i=0; i<=nLeafPoints/2;i++) {
    xOutline[i] = 2*i/(float)(nLeafPoints);
    yOutline[i] = (-pow((xOutline[i]-.5), 2)+.25);
    if (i>0 && i<=nLeafPoints/2) {
      xOutline[nLeafPoints-i] = xOutline[i];
      yOutline[nLeafPoints-i] = -yOutline[i];
    }
  }
}
float tempx;
float tempy;
//leafWidth is a fraction of leafLength
void drawLeaf(float x, float y, float leafLength, float leafWidth, float direction) {
  beginShape();
  for (int i=0; i<xOutline.length;i++) {
    tempx = xOutline[i]*cos(direction)*leafLength-yOutline[i]*sin(direction)*leafWidth*leafLength;
    tempy = xOutline[i]*sin(direction)*leafLength+yOutline[i]*cos(direction)*leafWidth*leafLength;
    vertex(x+tempx, y+tempy);
  }
  endShape(CLOSE);
}
```

Leave Code: Structure

```
class leaf {
  float theta0, dTheta, myWidth, myLength;
  int index;
  leaf(float thetaBranch, int index0) {
    theta0 =
thetaBranch+randomSign()*random(PI/6, PI/3);
    dTheta = 0;
    myWidth = random(minWidth, maxWidth);
    myLength = random(minLength, maxLength);
    index = index0;
  }
  void moveFromWind() {
    float dThetaWind = (((theta0+dTheta)-
windDirection)%TWO_PI);
    if (dThetaWind>PI)
      dThetaWind = -(TWO_PI-dThetaWind);
    else if (dThetaWind<-PI)
      dThetaWind = TWO_PI+dThetaWind;
    theta0 = (theta0+TWO_PI)%TWO_PI;
    float forceOfLeaf = -(dTheta)/(PI);
    float forceOfWind = -
windVelocity*sin(dThetaWind);
    float LeafForce = ((noise(random(20, 30)))*30);
    dTheta +=
(forceOfLeaf+forceOfWind)/LeafForce;
    smooth();
  }
  void rotate(float deltaTheta) {
    dTheta+= deltaTheta;
  }
  void draw(float x, float y) {
    float LeafJitter = (-
windVelocity*sin((((theta0+dTheta)-
windDirection)%TWO_PI))) ;
    drawLeaf(x, y, myLength, myWidth,
((theta0+dTheta)+(random((LeafJitter))*.5)));
  }
  void draw(float[] coord) {
    draw(coord[0], coord[1]);
  }
}
```

Branch/ Leaf Structure and code format derived from "Trees in the Wind" by Esteban Hufstedler, licensed under Creative Commons Attribution-Share Alike 3.0 and GNU GPL license.

Work:
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Wind Code: Artificial

```
float windDirection;
float windVelocity;
float velIncrement = random(0.01, 0.10);
float velOff = 0;
float windspeedIncrement = random(.1,.5);
float windspeed = 0;

void updateWind() {
  velOff+= velIncrement;
  windDirection = (windDirection+random(-1, -1)*.001+TWO_PI)%TWO_PI;
    windspeed+= windspeedIncrement;
  if (windspeed >= 2.1 ) {
    windspeed-= windspeedIncrement;
  }
   windVelocity = (windspeed)*noise(velOff)-1;
}
```

Live Input: Wind Sensor Input Setup

```
import processing.serial.*;
Serial myPort;  // The serial port:
int inByte;
int dir;
int vel;
void serialSetup() {
  println(Serial.list());
  myPort = new Serial(this, Serial.list()[0], 9600);
}
void liveWind() {
  while (myPort.available () > 0) {
    inByte = myPort.read();
    // println(inByte);
    liveDirection();
  }
}
void liveDirection() {
  dir = inByte;
  /*if (inByte == 'W'){
   windDirection = 0;
   println(windDirection);
   updateWind();}
   }*/
  if (dir == 255) {
    println("E");
    windDirection = random(-.5, .5);
  }
  else if (dir == 250 || dir == 251) {
    println("NW");
    windDirection = random(.7, 1.1);
  }
  else if (dir == 236) {
    println("N");
    windDirection = random(1.25, 1.75);
  }
  else if (dir == 222) {
    println("NW");
    windDirection = random(2, 2.5 );
  }
  else if (dir == 193) {
    println("W");
    windDirection = random(2.75, 3.25);
  }
  else if (dir == 246) {
    println("SW");
    windDirection = random(5, 5.5);
  }
  else if (dir == 253) {
    println("S");
    windDirection = random(4.25, 4.75);
  }
  else if (dir == 254) {
    println("SE");
    windDirection = random(3.75, 4);
  }
  else if (dir <= 25) {
    liveVelocity();
  }
}
void liveVelocity() {
  vel = dir;
  windVelocity = vel;
  //println(vel);
  //println(windVelocity);
  //updateWind();
}
```

User Interface Setup

```
import processing.serial.*;
Serial myPort;

int inByte;
int dir;
float vel = random(0.01, 0.10);
float mul =2;
int speed;
float treeForce = 1.25;
float leafForce = 1;
float LeafJitter;
PFont fnt;
float wDirection;
float wFrequency;
float wSpeed;
float bStrength;
float lStrength;

void serialSetup() {
  println(Serial.list());
  myPort = new Serial(this, Serial.list()[0], 9600);
}

void userWind() {
  while (myPort.available () > 0) {
    inByte = myPort.read();
    // println(inByte);
    userInput();
  }
}
void userInput() {
  if (inByte < 50) {
    dir = inByte;
    windDirection = map (dir, 1, 50, 0, TWO_PI);
    //println(windDirection);
    wDirection = round (map (windDirection, -.12,
6.15, 360, 0));
  }

  if (inByte >50 && inByte < 100) {
    // int velo = inByte;
    vel = map (inByte, 51, 100, 0, .15);
    // println(vel);
    wFrequency = round (map (vel, 0, .15, 10, 0));
  }

  if (inByte >100 && inByte <150) {
    speed = inByte;
    mul = round (map (speed, 101, 150, 11, 1));
     //println(windVelocity);
    wSpeed = round( map(windVelocity, -.5, 5, 0,
10));
  }

  if (inByte >150 && inByte<200) {
    treeForce = map(inByte, 151, 200, 10, 0);
    //println(treeForce);
    bStrength = round(treeForce);
  }

  if (inByte>200 && inByte <250) {
    leafForce = map(inByte, 201, 250, 1, 25);
    // println(leafForce);
    lStrength = round( map(leafForce, 1, 25, 0,
10));
  }
}
```

Text Readout Setup For User Interface

```
PFont font;
void textdraw() {
   textFont(font,18);

  fill(255);
  rect (0,height-50,width,45);

  fill(0);
  textAlign(CENTER);
   text( "wind direction:" + wDirection + "  |  "
   + "wind frequency:" + wFrequency + "  |  "
   + "wind speed:" + wSpeed + "  |  "
   + "branch strength:" + bStrength + "  |  "
   + "leaf strength:" + lStrength, (width/2),(height-35));
   }
```

User Controlled Wind

```
float windDirection;
float windVelocity;
float velOff = 0;
float windMult;
void updateWind() {
  velOff+= vel;//  velIncrement;
  windMult = mul;
  windDirection = (windDirection+random(-1, -1)*.001+TWO_PI)%TWO_PI;
  windVelocity = windMult*noise(velOff)-1;

  // println (velOff);
  //println(windVelocity);
}
```

Live Wind

```
float windDirection;
float windVelocity;
float velOff = 0;
float speed = 2;

void updateWind() {
  velOff+= vel;
  speed = map(vel, 0, 20, 1, 7);
  windDirection =(windDirection+random(-1, 1)*.001+TWO_PI)%TWO_PI;
  windVelocity = (speed)*noise(velOff/50)-1;
```

Arduino Code: Physical Interface For Digital Shadow

```
// to the pins used:
const int analogInPinONE = A0;  // Analog input
pin that the potentiometer is attached to
const int analogInPinTWO = A1;
const int analogInPinTHREE = A2;
const int analogInPinFOUR = A3;
const int analogInPinFIVE = A4;

int stateValueONE;
int stateValueTWO;
int stateValueTHREE;
int stateValueFOUR;
int stateValueFIVE;

int sensorValueONE = 0;        // value read from
the port
int sensorValueTWO = 0;
int sensorValueTHREE = 0;
int sensorValueFOUR = 0;
int sensorValueFIVE = 0;

int outputValueONE;
int outputValueTWO;
int outputValueTHREE;
int outputValueFOUR;
int outputValueFIVE;

void setup() {
  // initialize serial communications at 9600 bps:
  Serial.begin(9600);
  stateValueONE = analogRead(analogInPinONE);
  stateValueTWO =
analogRead(analogInPinTWO);
  stateValueTHREE =
analogRead(analogInPinTHREE);
  stateValueFOUR =
analogRead(analogInPinFOUR);
  stateValueFIVE = analogRead(analogInPinFIVE);
}

void loop() {
  // read the analog in value:
  sensorValueONE =
analogRead(analogInPinONE);
  sensorValueTWO =
analogRead(analogInPinTWO);
  sensorValueTHREE =
analogRead(analogInPinTHREE);
  sensorValueFOUR =
analogRead(analogInPinFOUR);
  sensorValueFIVE =
analogRead(analogInPinFIVE);

  // map it to the range of the analog out:
  if (sensorValueONE != stateValueONE &&
sensorValueONE != (stateValueONE + 1) &&
sensorValueONE != (stateValueONE - 1) &&
sensorValueONE != (stateValueONE + 2) &&
sensorValueONE != (stateValueONE - 2) ){
    outputValueONE = map(sensorValueONE, 0,
1023, 0, 50);
    Serial.write(outputValueONE);
    stateValueONE = sensorValueONE;
  }

  if (sensorValueTWO != stateValueTWO &&
sensorValueTWO != (stateValueTWO + 1) &&
sensorValueTWO != (stateValueTWO - 1) &&
sensorValueTWO != (stateValueTWO + 2) &&
sensorValueTWO != (stateValueTWO - 2) ){
    outputValueTWO = map(sensorValueTWO, 0,
1023, 51, 100);
    Serial.write(outputValueTWO);
    stateValueTWO = sensorValueTWO;
  }

  if (sensorValueTHREE != stateValueTHREE &&
sensorValueTHREE != (stateValueTHREE + 1)
&& sensorValueTHREE != (stateValueTHREE -
1) && sensorValueTHREE != (stateValueTHREE
+ 2) && sensorValueTHREE !=
(stateValueTHREE - 2) ){
    outputValueTHREE =
map(sensorValueTHREE, 0, 1023, 101, 150);
    Serial.write(outputValueTHREE);
    stateValueTHREE = sensorValueTHREE;
  }

  if (sensorValueFOUR != stateValueFOUR &&
sensorValueFOUR != (stateValueFOUR + 1) &&
sensorValueFOUR != (stateValueFOUR - 1) &&
sensorValueFOUR != (stateValueFOUR + 2) &&
sensorValueFOUR != (stateValueFOUR - 2) ){
```

Arduino Code: Physical Interface For Digital Shadow Continued

```
    outputValueFOUR = map(sensorValueFOUR,
0, 1023, 151, 200);
    Serial.write(outputValueFOUR);
    stateValueFOUR = sensorValueFOUR;
  }

  if (sensorValueFIVE != stateValueFIVE &&
sensorValueFIVE != (stateValueFIVE + 1) &&
sensorValueFIVE != (stateValueFIVE - 1) &&
sensorValueFIVE != (stateValueFIVE + 2) &&
sensorValueFIVE != (stateValueFIVE - 2) ){
    outputValueFIVE = map(sensorValueFIVE, 0,
1023, 201, 250);
    Serial.write(outputValueFIVE);
    stateValueFIVE = sensorValueFIVE;
  }
    // print the results to the serial monitor:
  //Serial.print("sensor = " );
  //Serial.println(sensorValueONE);

  // wait 2 milliseconds before the next loop
  // for the analog-to-digital converter to settle
  // after the last reading:
  delay(2);      }
```

Arduino Code: Reading And Interpreting The Wind Vane And Anemometer

```
#define uint  unsigned int
#define ulong unsigned long
#define SpeedPin  2     // Digital 2
#define SpeedCalcMsecs 5000
volatile int numRevsAnemometer = 0; //
Incremented in the interrupt
ulong nextCalcSpeed;                // When we next
calc the wind speed
ulong time;                         // Millis() at each start
of loop().
int sensorPin = 5; // Select input pin
int val = 0;

void setup() {
  Serial.begin(9600);
  pinMode(SpeedPin, INPUT);
  digitalWrite(SpeedPin, HIGH);
  attachInterrupt(0, countAnemometer,
FALLING);
  nextCalcSpeed = millis() + SpeedCalcMsecs;
}

void loop() {
  time = millis();
  if (time >= nextCalcSpeed) {
    WindDirection();
    calcWindSpeed();
    nextCalcSpeed = time + SpeedCalcMsecs;
  }
}

void countAnemometer() {
  numRevsAnemometer++;
}

void WindDirection() {
   val = analogRead(sensorPin); // Read value from
sensor
  val >>=2;
  switch (val) {
    case 255:
      Serial.println("W");
     break;
    case 254:
       Serial.println("NW");
     break;
    case 253:
       Serial.println("NW");
     break;
    case 250:
      Serial.println("SW");
     break;
    case 246:
      Serial.println("NE");
     break;
    case 236:
      Serial.println("S");
     break;
    case 222:
      Serial.println("SE");
     break;
    case 192:
      Serial.println("E");
     break;
   default:
     Serial.println(val);
  }
}

void calcWindSpeed() {
  int x, iSpeed;
  long speed = 14920;
  speed *= numRevsAnemometer;
  speed /= SpeedCalcMsecs;
  iSpeed = speed;

  // Serial.println("Wind speed: ");
  x = iSpeed / 10;
  Serial.println(x);
  // Serial.print('.');
  //x = iSpeed % 10;
  //Serial.print(x);

  numRevsAnemometer = 0;        // Reset counter
}
```

APPENDIX E

ANNOTATED REFERENCES

Bringslimark, Tina, Terry Hartig, and Grete G. Patil. "Adaptation to Windowlessness: Do Office Workers Compensate for a Lack of Visual Access to the Outdoors?" *Environment and Behavior* 43, no. 4 (2011): 469-487.

The author's intent was to find out if workers in windowless offices are more likely to bring in plants or put up posters. A survey of Norwegian office workers was conducted in multiple office situations. The findings suggested that "that windowless office workers had roughly five times greater odds of having brought plants into their workspaces than workers with a window view, and they had over three times greater odds of having brought pictures of nature into their work-spaces." (pg. 479-480) The major limitations of the study were the fact that the companies surveyed used a plant supplier as wells as the geographic limitation.

Bringslimark, Tina, Terry Hartig, and Grete G. Patil. "The Psychological Benefits of Indoor Plants: A Critical Review of the Experimental Literature." *Journal of Environmental Psychology* 29, no. 4 (2009): 422-433.

This articles main focus is on the benefits gained through every day, or passive, interactions with indoor plants rather than those in more guided interactions with plants such as horticultural therapy or the indirect effect of indoor plants as air purifiers or humidifiers. The experiments addressed a variety of outcomes, including emotional states, pain perception, creativity, task-performance, and indices of autonomic arousal.

Collins, Belinda L. *Windows and People: A Literature Survey. Psychological Reaction to Environments with and Without Windows.* No. NBS-BSS-70. National Bureau of Standards, Washington, DC (USA); US Dept. of Commerce, National Bureau of Standards, Institute for Applied Technology, Washington, DC 20234, 1975.

A large collection of research looks at windowlessness in a variety of contexts including schools and the workplace. The psychological positives and negatives are also described.

Edwards, J. "Daylighting as a Supplement to Electric Illumination." *BT Arch dissertation, Ryerson Polytechnical Institute, Toronto* (1978).

Unpublished Dissertation from Heerwagen's "Psychological Aspects of Windows and Window Designs" p.273. Suggested that we are spending too much of our time using electric lighting, most by necessity-since everyday work environment often does not have windows.

Farley, Kelly M., and Jennifer A. Veitch. *A Room with a View: A Review of the Effects of Windows on Work and Well-Being.* Institute for Research in Construction, National Research Council Canada, 2001

This report looked broadly at the effects of windows on people. It assesses the use and need for windows as well as the physical and psychological benefits. It references several other studied comparing situations with and without windows. Schools, offices, hospitals and homes are addressed. It is a plethora of gathered information about the effects of windows and the adverse effects of windowlessness.

Friedberg, Anne. *The Virtual Window: From Alberti to Microsoft.* MIT Press, 2006.

The definitive book on virtual windows. It discusses the progression of the virtual window through the ages and the contexts that inspire and accommodate them. Perspective in paintings, televisions, computers for example. The architectural role of the screen, for example, is also discussed.

Goldberger, Leo. "Sensory Deprivation and Overload." In *Handbook of Stress: Theoretical and Clinical Aspects*, edited by Leo Goldberger and Shlomo Breznitz, 333-335. Simon and Schuster, 1993.

This research covers the spectrum with regards to sensory stimulation or lack thereof. The particular area of use for this study was the section on boredom (page 335) discussing the potential for daydreaming and the consequential potential to affect performance.

Hebb, Donald O. "Drives and the Conceptual Nervous System." *Psychological Review* 62, no. 4 (1955): 243.

This article focused on the optimal level of stimulation. The Psychological evidence shows that there is a range in human motivation from deep sleep to strong emotion; the optimal levels for "adaptive behavior" is somewhere in the middle. An aspect of this article is the 15 minute boredom wall.

Heerwagen, Judith H. "The Psychological Aspects of Windows and Window Design." In *Proceedings of 21st Annual Conference of the Environmental Design Research Association. Oklahoma City: EDRA.* 269-280. 1990.

The paper suggests that there are four general benefits of windows: (1) access to environmental information; (2) access to sensory change; (3) a feeling of connection

to the world outside; and (4) restoration and recovery. (p. 269) Each is examined. Additionally, the concept of "To See Without Being Seen" is suggested a method of finding comfort. Examples of spaces include the "fish bowl" or atrium, "interrogation room" or windowless room with someone watching you, "The Cave" or windowless room with no view. The paper also examines how occupants use more visual décor, and examines other methods, concluding with a call for new strategies.

Iltis, Hugh H. "Can One Love a Plastic Tree?" *Bulletin of the Ecological Society of America* (1973): 5-19.

This article is almost always tied to the one by Kreiger. Iltis is taking the naturalist side of the argument equating plastic trees to human dolls and to say a plastic tree is equal to a real one is like saying we can live dolls the same as babies.

Kahn, Peter H., *et.al.* "A Plasma Display Window?—The Shifting Baseline Problem in a Technologically Mediated Natural World." *Journal of Environmental Psychology* 28, no. 2 (2008): 192-199.

This article tested the effectiveness if a HDTV real-time view of nature. The test consisted of 90 office members looking through a glass window, the television, and a blank brick wall. The key results found that in terms of heart rate, the glass window was most effective, with the television not much more effective than the wall. There are also suggestions on why the benefits of viewing nature may be diminished by a digital medium.

Kahn Jr, Peter H., Rachel L. Severson, and Jolina H. Ruckert. "The Human Relation with Nature and Technological Nature." *Current Directions in Psychological Science* 18, no. 1 (2009): 37-42.

This article examined technologies that in various ways mediate, augment, or simulate the natural world. Current examples of technological nature include videos and live webcams of nature, robot animals, and immersive virtual environments. The article questions whether it matters if actual nature is being replaced with technological nature? (Yes)They finish by addressing "environmental generational amnesia" which essentially is the concern that humans in the coming generations will gradually begin adapting technology to the point where they cannot tell the difference between technological nature and actual nature. Key studies include a preference test with CCTV, finding it less effective than a window.

Kahn Jr, Peter H. "Environmental Generational Amnesia"." In *Technological Nature: Adaptation and The Future of Human Life*, 163-183. MIT Press, 2011.

This chapter is a warning of sorts, as we spend or of our time indoors and develop technologies, the next generations could potentially take nature for granite, and easily forget or never know what nature is.

Kahn Jr, Peter H. *Technological nature: Adaptation and the Future of Human Life*. MIT Press, 2011.

This book was the most informative to this research, though it wasn't published until after starting research, the projects presented in this book became inspirations for comparisons on the human subject study. The "office window of the future" and

"technological view of nature" experiments helped inform the experiment design for this

Kaplan, Rachael, and Stephen Kaplan. "Adolescents and the Natural Environment: a Time Out?" In *Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations,* by Peter H. Kahn Jr, and Stephen R. Kellert, eds., 227-258. MIT Press, 2002.

This selection addressed the relationship of teenagers and adolescents to the natural environment. They goal of the research is to determine if they have different values than others. They compare picture preferences, with different types of settings. Finding suggest time spent outdoors has attention restoration benefits

Kaplan, Rachel, and Stephen Kaplan. *The Experience of Nature: A Psychological Perspective.* Cambridge University Press, 1989.

This book is an analysis of the psychological role that nature plays. addressed how people perceive nature and what types of natural environments they prefer, the psychological benefits they seem to derive from wilderness experiences, satisfactions and advantages that various natural settings bring to us, intuitive effects of nature, restorative bodily health, and an examination of effective patterns.. Key concept: attention restoration through natural imagery

Kaplan, Stephen. "The Restorative Benefits of Nature: Toward an Integrative Framework." *Journal of Environmental Psychology* 15, no. 3 (1995): 169-182

In this study the effects of nature on attention and restoration are explored. The level of fatigue depends on the task at hand as does the distraction. Nature can mediate stress and improve productivity.

Krieger, Martin H. "What's Wrong with Plastic Trees?: Rationales for preserving rare natural environments involve economic, societal, and political factors." *Science* 179, no. 4072 (1973): 446.

This article was rather controversial in some circles when it was released, it evoked responses like those by Iltis who thought it was blasphemous to their worldview. He questions highlights that since humans adapt to so many ither things, why can they adapt to plastic trees.

Lohr, Virginia I., Caroline H. Pearson-Mims, and Georgia K. Goodwin. "Interior Plants May Improve Worker Productivity and Reduce Stress in A Windowless Environment." *Journal of Environmental Horticulture* 14 (1996): 97-100.

The research questioned whether the presence of plants in a windowless room affects productivity or stress levels. The focus of the research is a series of preference surveys issued to subjects that were asked to complete a task in a windowless computer lab with or without windows. The subjects were primarily college students asked to complete a computer program in the controlled room. Stress was moderately affected based on blood pressure and there was an increase in productivity (reaction time). The study is limited by a non-realistic singular task and a short-term survey.

Nute, Kevin, *et.al.* "The Animation of the Weather as a Means of Sustaining Building Occupants and the Natural Environment." *The International Journal of Environmental Sustainability,* 1 (2012).

An article currently awaiting publication examining the effects of natural elements such as rain an wind on occupant comfort. They introduce change into a space an monitor the effects it has on the space and occupant.

Paciuk, Monica. "The Role of Personal Control of the Environment in Thermal Comfort and Satisfaction at the Workplace." PhD diss., University of Wisconsin-Milwaukee, 1989.

This paper examined the impact being able to control things such as thermostat or window blind has on the percived comfort in a worksace. It supported some of the findings of this research favoring personal conrtrol

Partridge, Ernest. "Ecological morality and Nonmoral Sentiments." *Land, Value, Community: Callicott and Environmental Philosophy* (2002): 21.

This article pushes for awareness and care for the natural environment. The particular area of interest of this article was the examination of the plastic tree conundrum and its repercussions

Radikovic, Adrijan S., John J. Leggett, John Keyser, and Roger S. Ulrich. "Artificial Window View of Nature." In *CHI'05 extended abstracts on Human factors in computing systems*, pp. 1993-1996. ACM, 2005.

The authors examined current window substitutes including still images and video stating that they lack dimensional properties necessary for a realistic viewing experience – primarily motion parallax. The article present their solution: a virtual window using a head- coupled display and image-based rendering to simulate a

photorealistic artificial window view of nature with motion parallax. The evaluation data obtained from a group of human subjects suggest that the system prototype is a better window substitute than a static image. The test subjects judged it much higher ratings for realism and preference than a static image. The shortcomings of this experiment are no live connection and high price.

Riley, Robert B. "Attachment to the Ordinary Landscape." In *Place attachment,* edited by Irwin Altman and Setha M. Low, 13-35. Plenum Press, 1992.

This chapter examines the difference between preference and need for nature. Preference being what is examined by research like that Kaplan and this study and need which is inherent human behavior that Iltis argues for, with regard to the plastic tree.

Ruys, Theodorus. "Windowless offices." PhD diss., University of Washington., 1970.

Unpublished master's thesis included in Farely and Veitch's review of literature. Primary focus of the thesis was the survey of office workers to address how windowless environments affect them.

Schneider, Stephen Henry, and Lynne Morton. *The Primordial Bond: Exploring Connections Between Man and Nature Through the Humanities and Sciences.* Plenum Press, 1981.

This book discusses in length how the inherent connection to the natural environment informs everything that we as a species do.

Stone, Nancy J., and Anthony J. English. "Task Type, Posters, and Workspace Color on Mood, Satisfaction, and Performance." *Journal of Environmental Psychology* 18, no. 2 (1998): 175-185

This study examined the effects of workplace decor and color on worker emotion and efficiency. Primarily looking at Color of the workplace and posters, controlled tests are setup to compare environments. Students are used as subjects, randomly assigned to a type of space, and not reused. Key findings include that red color leads into increase in productivity, blue interiors are calming and therefore less productive, and people with posters are less likely to look around that those without. The study contains results as quantitative data and thusly limits findings.

Tuan, Yi-Fu. "Man and Nature." Resource Paper 10, Commission on College Geography, Washington, DC: Association of American Geographers, 1971

This resource paper examines how humans adapt to their enironment by manipulaing it. It specifically looks at how humans affect, and are inspired by, natural Geological forms.

Ulrich, Roger. S., Robert F. Simons, and Mark A. Miles. "Effects of Environmental Simulations and Television on Blood Donor Stress." *Journal of Architectural and Planning Research* 20, no. 1 (2003): 38-47.

This study measured stress levels (blood pressure, pulse rate) of 872 blood donors in four conditions using wall-mounted television monitors: a videotape of nature settings (Nature); a tape of urban environments (Urban); daytime television (Television); or a blank monitor (No Television). Finding that stress was lower during No Television than Television and during Low Stimulation (No Television + Nature)

than High Stimulation (Television + Urban). pulse rates were markedly lower during Nature than Urban. The study compared the impact a television can have on patients, suggesting a natural substitute is better than none at all.

Ulrich, Roger. "View through A Window May Influence Recovery." *Science* 224 (1984): 224-225.

This study examined medical records on patient recovery hospital between 1972 and 1981 to determine whether assignment to a room with a window view of a natural setting might have restorative influences. Twenty-three surgical patients assigned to rooms with windows looking out on a natural scene had shorter postoperative hospital stays, received fewer negative evaluative comments in nurses' notes, and took fewer potent analgesics than 23 matched patients in similar rooms with windows facing a brick building wall.

Additional Resources

Catherine, Mary, and Kenneth S Horn. “A Room With No View.” *New York Times*. July 3, 2005

This article details a recent trend to convert office buildings to condominiums in New York City, a process that results windowless rooms. The windowless spaces cannot be sold as bedrooms so they are rebranded as offices or TV rooms. In one project mentioned 13 of the 45 units had a windowless room. The units with a spare windowless room often cost less.

Cusack, Pearce, Louise Lankston, and Chris Isles. "Impact of visual art in patient waiting rooms: survey of patients attending a transplant clinic in Dumfries." *JRSM short report* no.6 (2010): 52.

The study attempted to find the most important aspects of a patient waiting room. The primary means study was a survey given to the people using the clinic. Questions focused on importance of objects in the space. Chairs being most important, then TV, then paintings all interestingly above the window. The study is limited by use of a single space and arrangement. It would be interesting to see the results if there were no window.

Dijkstra, Karin, Marcel Pieterse, and Ad Pruyn. "Physical environmental stimuli that turn healthcare facilities into healing environments through psychologically mediated effects: systematic review." *Journal of advanced nursing* 56, no.2 (2006): 166-81.

This study looked specifically at factors that have psychological impacts as opposed to psychological impacts. The information is based on the collective knowledge of 30 articles. Topics are divided into stimuli, ambient features, architectural features, and interior design. The effects of each are detailed within subtopics. The comparison of television to no television and television to natural elements is useful.

Funka-Lea, G., and R. Bajcsy. "Combining color and geometry for the active, visual recognition of shadows." In *International Conference on Computer Vision* 203. IEEE Computer Society, 1995.

The study focused on the detection of shadows as they relate to a scene. It is proposed that given a number of cues, it can be determined the light source of a specific shadow. Cues tested include the color, hue, brightness, and geometry. Both indoor and outdoor scenes were tested, however multiple concurrent light sources were not.

Variables were used to create an Algorithm that was then used for tests. Objects were successfully recognized in controlled tests but even then, additional shading was mistaken for shadows

Knez, I., and C. Kers. "Effects of Indoor Lighting, Gender, and Age on Mood and Cognitive Performance." *Environment and Behavior* 32, no.6 (2000): 817-831.

This study questioned the link between lighting and a task specifically addressing the variables of gender and age. The study tests to see if color tones, cool and warm are perceived differently by male and females in different age groups. Older females notice most change, younger males notice least. A small test group limits the test and tests results were based on recollection, which has many other variables.

Korpela, K. M., T. Klemettila, and J. K. Hietanen. "Evidence for Rapid Affective Evaluation of Environmental Scenes." *Environment and Behavior* 34, no. 5 (2002): 634-650.

The focus of this psychological study was to prove that humans find it easier to find positive in nature than in the urban environments. Twenty-eight human subjects were shown pictures of nature or urban environment followed by a one-word phrase and asked if it was positive or negative. People respond quicker with a natural image. Test was subject to random picture phrase pairing as well as reaction time of subjects.

Mendes, Mónica. "RTiVISS | Real-Time Video Interactive Systems for Sustainability" (2010)

This project brought live video of forests into buildings using wireless cameras. The goal of the exploration is to provide awareness to the forests of the world. They add an interactive aspect allowing people to set it on fire, subtract from it, or digitally link a user to a tree. It also links to the web so people can see on a map where they are

looking live. The study is not directly architectural but the digital conveyance of nature is directly applicable to my research.

Nagy, E. "Japanese office employees' psychological reactions to their underground and above-ground offices." *Journal of Environmental Psychology* 15, no. 2 (June 1995): 123-134.

The purpose of this study was to find if people in eastern culture were equally as uncomfortable in windowless environments as their western counterparts. A surgery was given to 98 workers evaluating window preference and lighting levels. Environmental factors such as noise, color temperature, and furniture were similar. Being underground has additional psychological impacts. The study is limited by its breadth but makes that point that people everywhere like windows.

Summit, J., and R. Sommer. "Further Studies of Preferred Tree Shapes." *Environment and Behavior* 31, no. 4 (July 1, 1999): 550-576.

The purpose of this study was to find the most appealing tree form. The researchers use three different studies to generate a conclusion. The first was to place a form into a context. The second was to classify was to pick the tree that provided to most refuge. The third was to pick a shape that was most appealing. In all three cases, the wide canopy form was chosen. This is useful to know since a method of transmitting change is through movement of trees. A representation of this form could be used as a shadow casting shape. An aesthetically pleasing form is more likely to draw attention as well.

Sylvester, Ginny. “Interactive Installations and the Conception of Space.” *The 2nd IET International Conference on Intelligent Environments IE 06, 05-06 July 2006, National Technical University of Athens, Greece I* (December 2006): 71-74.

This Conference Introduction focused on the connection between the mediums of the digital and built form, of art and architecture. It addresses the ideal of virtually and the opportunities to work with the site, or not to, and to reinvent the interface of a building. He also introduced several interesting projects. This is useful because it is of the same mindset of my project, bridging the build and virtual within the architectural environment.

Zarin, Rouien, and Daniel Fallman. “Ambient Interactive Architecture: Enriching Urban Spaces with Low-cost, Lightweight Interactive Lighting.” *Design* (2010): 296-301.

The article details their interactive installations in a pedestrian tunnel in northern Sweden. The purpose of the installation was to portray the happenings of the road above to the tunnel below. They chose abstract "northern lights" to show this change. They were standard green and changed to red and yellow when a car or truck passed. They showed that they could dramatically change the space, while remaining an ambient condition and connecting to its surroundings.

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