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ABSTRACT
People continue to buy smart home devices in record numbers, but research shows that some find them less useful. We argue that one reason may be that of usability, not of one device, but of the entire smart home system. Most research concerning smart home technology focuses on individual devices such as the smart home hubs with smart assistants. In contrast, our usability study targets a full smart home set of devices comparable to that of an average living room, where most people would use those devices. Results from our usability study of a Google smart home set up as a living room in a laboratory show that some aspects of the technology are user-friendly, but that usability issues remain significant.

CCS Concepts
Human-centered computing

Keywords
Smart home, Usability, Google, User-centered design, Technology diffusion

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INTRODUCTION
Many articles have appeared during recent years concerning the topic of smart home technology (SHT). Smart home technology was defined by Marikyan et al. (2019) as devices that have interconnection with the Internet of Things, interoperability, monitoring, control, and some "degree of artificial intelligence" that combine to provide "information from the surrounding environment and act accordingly to increase the well-being of people" (139). Some of the benefits that have been claimed by smart home devices include enhanced energy management, improved security, enhanced leisure and entertainment services, and "extended personal independence through healthcare provision and assisted living" (Wilson et al., 2017, p. 73).

According to research provided by Hargreaves et al. (2018), the main purposes for smart home technologies are "making life at home more convenient, providing security, and enhancing entertainment and communication" (p. 76). However, as Brush et al. (2011) have shown, smart home technologies are now forty years old. Despite this, available technology systems have not been widely adopted. Unlike most studies, Brush et al.'s research utilized homes with existing technology and pointed to four primary reasons for lackluster sales, including high cost of ownership, inflexibility, poor manageability, and poor security. This pattern is not dissimilar to other electronic technologies such as computers. As Cortada (2013) has shown, information technologies, including computers, were not widely adopted until they became less expensive and easier to use than their early counterparts. In the case of SHT, much of their failure continues to proliferate because they are still difficult to operate (Fleishman, 2019).

But people do seem to be buying them. According to Lardinois (2018), Google has reported selling a smart Google Home device every second, and as of 2020 more than 200 million smart home devices have been sold around the world (Sterling, 2020). Amazon has stated in 2019 that 100 million products with the built-in "Alexa" voice assistant have been sold (Hartmans, 2019). However, a large majority of those devices are smart televisions and voice assistants. Thormundsson (2022) reported that although

76% of households now have a smart television, only 32% have smart voice assistants and not more than 25% of households have any other type of smart device. So, a large majority of those devices sold are simply televisions and voice assistants, with most people never adding additional devices. Otherwise, many more potential users would report having adopted smart home technology systems. However, it is also likely that a good percentage of users have tried the technology and then rejected it before fully adopting it. Some of this can be attributed to bad experiences (Shank et al., 2022) but the difficulty in using the devices is probably an even larger driver of discontinuance (Knott, 2018).

In this paper, we overview the literature on different non-adoption processes, use, and usability of smart home technology. Then we overview a laboratory-based usability study of a smart home, that is an entire system of connected smart home devices. We present and analyze the results of 30 tasks in this study drawing out conclusions and applications for future work.

Not Adopting Smart Home Technology

Wolverton and Cenfetelli (2019) examined the factors surrounding the decision not to adopt a technology. Their results point to the fact that there are different types of non-adopters based on perceptions among users. Those types include trial rejectors, symbolic rejectors, trial acceptors, symbolic adopters, and adopters. Trial adopters are concerned that learning the innovation would require more time (outweigh) than the benefits they might gain. This perception is based on investigative analysis. Symbolic adopters consider adopting the technology for more emotional reasons. In contrast, trial rejectors try a new technology but tend to reject it based on loyalty to their current technology, while symbolic rejectors are apathetic concerning new technology. Although different variables contribute to each type of non-adopter, in the end, the result is the same unless adoption is undertaken. SHT research (Shank et al., 2022; Wright & Shank, 2020; Wright et al., 2021) has shown SHT users to be particularly similar to the trial adopters identified by Wolverton and Cenfetelli (2019) in that they are interested in SHT but rarely invest the time needed to maximize its benefits and quickly become disillusioned with difficult use.

However, more recently SHT has changed in that it is becoming more and more versatile in its operation. SHT devices can now be controlled using cell phones, voice commands through smart assistants, or in some cases through a visual interface connected to the assistants. Voice control has become a popular smart home assistant feature. Smart home devices are now used to control televisions, listen to music, search for facts, get the news, modify the lights and temperature in a home, order products, set alarms, and monitor health, among others. As their capacity and reliability increases, more are being sold. But research has shown that many users do not use the more complex features of interconnected smart home devices (Wilson et al., 2017; Wright & Shank, 2020). Therefore, acceptance and use of smart home products relies on users' perception of benefits and their concerns about using those devices.

So, what do users want? According to existing research, users want control over their home environment and products that are "designed to be reliable, easy to use, controllable, and easy to override" (Wilson & Hargreaves, 2017, p. 43). At the same time, users want technology to be secure and automation that does not make them overly dependent. Mennicken and Huang (2012) have shown that users are not necessarily awed by technology itself or the "gadgety" features of smart home technology. Instead, most take a more practical approach, saying that they, "do not see a benefit to automation if they could still perform the same task faster or better manually" (p. 150).

Hargreaves et al. (2018) conducted in-home research that points to complex learning demands placed on users as a strong detriment to utilizing smart home technology, saying, "there was little interest in this group in making use of the more advanced and automated features of the systems" (p. 134). Similar findings can be found in other research by Georgiev and Schlögl (2018) who found that insufficient interoperability, complexity, and lack of perceived value all hinder adoption of SHT; and research by Oliveira et. al (2015) that have shown SHT users are often overpowered by complex technology.

Use and Usability of Smart Home Technology

Despite these findings, there have been surprisingly few studies of SHT in lab-based settings, where actual use of SHT can be observed. Home-based studies are certainly valuable, in that they provide a perspective of use from a user's own living environment. However, without the ability to directly observe user interaction with SHT devices, researchers are dependent upon the recollections of subjects who are removed from the moment of use. Therefore, lab-based studies are needed in addition to home-based studies to provide a complete picture of use.

There has been some usability testing of SHT products, but much of this research focuses on health-related applications, especially those focusing on elder care and disability services. Studies such as Lim et al. (2016) examined the role that SHT can play in assisting wheelchair-bound users. Wray et al. (2017) examined SHT as an assistive technology for those living with HIV. Bissoli et al. (2019) proposed and tested an eye-tracking and monitoring system for SHT for those with severe disabilities, while other usability tests have focused on voice assistants for military veterans with brain injuries (Wallace & Morris, 2018).

Other usability studies have also been conducted to assist elder users with independent living. Some of the more recent studies include Dahmen et al.'s (2018) test of a digital notebook SHT device to help those with lapses in memory, Ghorayeb et al.'s (2021) study of elder users' perceptions of SHT, Hu et al.'s (2019) test of seniors' ability to install a pre-packaged SHT system, and Mieronkoski et al.'s (2022) study of SHT to assist with geriatric rehabilitation.

The number of usability-related studies that work with the average adult population is surprisingly limited and rarely focuses on the complete systems that offer the public the most complete range of advantages (multiple devices functioning together). While several studies mentioned above have dealt with SHT in houses, and some recent studies have examined user perceptions after a period of use (Oliveira et al., 2020), there have been few classic usability tests conducted with SHT. Some exceptions include Ur et al.'s (2014) study of user ability to program SHT "if, then" programming and Hu et al.'s (2019) study of a pre-packaged system for older adults. However, those studies did not test complete SHT systems that had been purchased "off the shelf." Instead, they focus on new designs for user control of SHT devices. There has been some usability testing conducted with smart home assistants. For example, López et al. (2017) compared the Natural User Interfaces of major smart home assistants (Alexa, Siri, Cortana and Google Assistant),

finding that traditional computing parameters do not work well for those devices. Likewise, Zwakman et al. (2021) tested the voice usability of Amazon's Alexa, proposing a voice usability scale to be used in evaluating other assistants. Again, those studies focus on one piece of the SHT environment, rather than a system of devices purchased for use together. In other words, they test the usability of smart home technologies, not the usability of integrated smart homes.

The study presented herein is a usability study of a Google smart home, conducted in a controlled laboratory setting. Specifically, we are not studying the usability of one device, but the entire network of devices that make a smart home. In contrast to home-based studies, we have set up a smart "living room" in a behavioral science laboratory to recruit participants to interact with the devices both in familiar ways (i.e., tasks that are typically done with smart home technology at home), but also not with one's own technology. Specifically, to provide the best usability test, we recruited participants with little experience with these devices. Therefore, aside from the insights on Google smart home products in general, our innovated methodology allows for a usability test of the entire suite of connected products in an ecologically valid way, without being biased by people's extensive experiences with the technology.

METHODS

We conducted a usability test (IRB exempt) on an integrated Google smart home set up in a behavioral science laboratory to emulate a living room setting. Our tests included 6 identification tasks, 22 individual action tasks, and 2 tasks to set up complex smart home routines.

Living Room Environment and Smart Home Devices

The tests were conducted in a small behavioral science laboratory room at Missouri University of Science and Technology made to feel somewhat like a living room with a couch, chair, side table, TV stand, coffee table, shelves, lamps, detached "external" door, and wall décor.

Because Google has recently added many new devices to its SHT lineup, we chose to use their technology. Those devices are new to the market and, therefore, pose new usability challenges. Also, because we were attempting to recreate a living room environment, we opted to purchase devices that would most typically be used in that room in a house. The smart home interface technologies included a Google Nest Hub Max, and the participant's choice of a Samsung Phone or iPhone, both in front of the couch on the coffee table. The smart home devices included a Phillips Smart TV, Smart Light Bulbs in 2 table lamps, a Google Nest Thermostat, a Google Nest Doorbell, Smart Door Lock, and Security Camera. The Smart Door Lock was attached to the detached "external" door and the Nest Doorbell and security camera were placed near it to simulate the front door of a house. The Nest Thermostat was mounted with lights near it to simulate whether the air or heat was running. Additionally, a locally installed Wi-Fi system was used to connect these devices and a video camera was placed in the room to video the study.

Most of these devices could be controlled in three ways: using the touchscreen of the Nest Hub Max, using voice commands (which were usually picked up by the Nest Hub Max's microphone), or via the Google Home app which was installed on both smartphones. Certain actions could not be performed by all devices: for example, the door lock could not be unlocked by voice commands for security reasons.

Testing Participants and Procedure

Undergraduate students who take introductory psychology must participate in a certain number of research study hours that semester but are open to any study they desire, are eligible for, and has open time slots. We recruited participants from this psychology research pool by posting our study to it. Potential subjects were asked to complete a screening questionnaire prior to joining the study (Appendix A). We wanted to be sure that we were testing subjects who did not have experience with SHT.

Eligibility was restricted by three questions, to ensure that participants did not have extensive experience with smart home technology. To be eligible to sign up for the study, students had never owned or lived with smart home devices ("*How many different kinds of smart home devices (e.g., Amazon Echo, Google Home, smart outlets, smart thermostat, smart locks) have you owned or lived in a home with?"* must be answered 0), had never set up smart home devices (*"Have you ever connected multiple smart home devices (e.g., Amazon Echo, Google Home, smart outlets, smart thermostat, smart locks)?"* must be answered *No*), and had never used the Google Home app ("*Have you ever used the Google Home app?"* must be answered *No*).

A total of twenty-seven participants signed up and completed our study. However, three of those participants were left out of our analysis due to faulty audio or video data. The total included 23 males and 4 females averaging 21.7 years old (18 to 54). Self-reported racial identification indicated that 17 participants were White, 4 multiracial, 3 Asian, 2 Black, and 1 did not specify. The participants' majors included 6 computer science/engineering, 4 engineering management, 2 English, 2 business, 2 mechanical engineering, 10 from other majors, and 1 not reporting. In addition to restricting the participants to ones with little smart home technology experience, we also asked them several questions about their use of technology to better profile our sample. All 27 of them reported using cell phone and computer systems, and 18 also used gaming systems, 15 used wearable or Bluetooth devices, 11 used smart TVs, 11 used other TV devices, 5 used smart watches, and only 1 used an iPod. The most common apps used by at least four participants were Snapchat (13), YouTube (9), Spotify (8), Instagram (7), Messages (5), and Reddit (4). Three participants reported having used a Google Nest Hub before.

Using university students has both advantages and limitations. Using technology-immersed students at a technology university, mostly in their late teens and early 20s, means that any errors they repeatedly make are most likely coming from poor usability design of the products, not because our sample is technology-illiterate. However, university students are not the typical demographic for owning homes and therefore we could expect differences for older individuals and homeowners. However, this concern is minimal, as we specifically were interesting in individuals who did not have smart home technology experience, meaning it is unlikely that older homeowners who had no smart home experience would be meaningfully different from younger non-homeowners who also did not have that experience.

Eligible participants could sign up for an open one-hour time slot

and then came to the lab at that time. One of two research proctors, a male and a female undergraduate student, conducted the study. Upon arriving at the lab, participants were asked to read and sign a consent form (Appendix E) explaining the study procedures. While data gathering and surveillance from the technology companies are large issues in SHT research in general (Ahanger & Aljumah, 2018; Komninos et al., 2014; Mantas et al., 2011), the nature of our research precluded them from being a major concern. These were not the participants' personal devices; and, therefore, personal information about the participants was not connected to the devices, and they were in the presence of a research proctor and agreed to be videoed, making the research surveillance most salient.

Next, they were asked to complete a pre-test questionnaire that was designed to collect more information concerning their use of technology and current attitudes toward SHT (Appendix B) and were given a choice of Apple or Android cell phone to use for the text. Participants were then asked to perform the set of tasks listed below, based on a script that was supplied to the research proctor (Appendix C).

Finally, participants were asked to complete a post-test questionnaire (Appendix D) which asked them to rate their overall opinions concerning SHT ease of use and to suggest improvements for the SHT. They were compensated with one hour credit for research participation.

Usability Tasks

The first set of six usability tasks were simply identifying six smart home technologies visible in the room: (1) Smart TV, (2) Nest Hub Max, (3) Hello Doorbell, (4) Smart Door Lock, (5) Smart Thermostat, and (6) Security Camera. The second set of 22 usability tasks were individual action tasks (Table 1). Participants were told the three methods to control the equipment: using the Nest Hub screen interface, using voice commands by saying "hey, Google" to the Nest Hub, or using the Google Home app on the smart phone. Some tasks could only be completed with certain methods due to technical limitations and other tasks we restricted to specific methods to focus on that method of control (see Table 1 for details). The third set of two usability tasks were to construct "Wake Up" and "Movietime" routines as described in a handout (Table 2). Routines are essentially command scripts that control multiple SHT devices simultaneously. Both routines were restricted to voice commands by technological limitations.

#	Task Name	Task Description	Methods Allowed
1	TV	Turn on the television.	Hub Voice[a]
2	Netflix	Start Netflix on the television.	Hub Voice[a]
3	Music	Using the Nest Hub, play music through the television.	Hub Screen
4	Volume	Using the Google Home app, change the volume of the television.	Phone
5	Next Song	Play the next song.	Any
6	Favorite Music	Play your favorite artist's music.	Any
7	Remove Weather	Alter the home display of the Nest Hub by removing the weather information.	Any
8	Alarm	Using the Nest Hub, set an alarm for five minutes from now.	Hub Screen[b]
9	Translate	Use the Nest Hub to translate the phrase, "Hello, would you like some coffee?" into Spanish.	Hub Voice[a]
10	Note	Create a family Nest Hub note for a specific time.	Hub Screen[b]
11	Lamp Count	Determine how many lamps are available for individual control within the room.	Any
12	Lamp On Hub	Using the Nest Hub, turn on the front lamp.	Hub Screen
13	Lamp On App	Using the Google Home app, turn on the table lamp.	Phone
14	Lamp Brightness	Set front lamp to 75% brightness and back lamp to 85%.	Any
15	Lamp Colors	Turn the front lamp green and the back lamp orange.	Any
16	Lamp Off	Set lamps to turn off in five minutes.	Hub Voice[a]
17	Doorbell Video	Access live video from the doorbell.	Any
18	Doorbell Voice	Speak through the doorbell.	Any
19	Lock Door	Using the Google Home app, lock the door.	Hub Phone
20	Security Video	Using the Nest Hub, access the video feed from the indoor security camera.	Hub Screen
21	Temperature Check	Check the current temperature of the thermostat.	Any
22	Temperature Change	Alter the current temperature of the thermostat.	Any

Table 1: Individual Action Tasks
[a] *These restrictions were due to technological limitations. Other restrictions were implemented as part of the task.*

[b] *We restricted these to Hub Screen, but many participants had to use the Hub Voice method to complete it.*

Wakeup Routine	Movietime
Create a new routine and name it “Wakeup.”	Create a new routine called “Movie Time.”
Edit the “Wakeup” routine to make it:	Edit the movie time routine to make it:
Activate when you say “Hey, Google, I’m awake.”	Have Nest Hub say, “Let’s Watch a Movie” when launched.
Turn lamps to 50% brightness with purple color.	Lock the door.
Change thermostat to 72 degrees.	Adjust the thermostat to 68 degrees.
Read the local weather forecast.	Adjust both lamp colors to green.
Read any calendar appointments for the day.	Turn on the TV.
Tell you if your phone battery is low.	
Play the news.	

Table 2: Routine Tasks: Instructions for making Routines

Proctoring, Recording, and Coding Usability Test

In general, we followed the testing and proctoring methods outlined by Barnum (2020) and Spool et al. (2008) including the use of Concurrent Think Aloud Protocol (asking participants to explain what they were doing and thinking during tasks), while additionally taking screen recordings of the cell phone in use and videotaping the sessions. However, we also drew from methodology suggested by Portigal (2013) in designing post-test questions for participants, from Hertzum’s (2020) discussion of testing user experience, and from Goodman et al.’s (2012) discussion of results analysis. Screen recordings and videotapes were later used for analysis, including determining time on task, number of errors per task, and the primary interactive method that was used to complete a task when there was a choice (voice, Next Hub, cell phone).

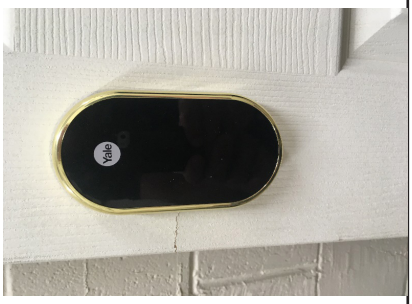
The research proctor sat in the living room area with the participant and directed them through the usability tests beginning with identification tasks, then individual action tasks, and finally complex routine tasks. During the test, the proctor encouraged participants to speak aloud as they performed the various tasks and were available to answer any questions. However, proctors were instructed not to answer questions that were beyond procedural concerns and to stop a particular task and move on if one minute elapsed without any significant progress toward the goal of the task. Due to the complexity of the routine creation tasks proctors allowed participants as much time as they needed to complete the task.

After all tests had been completed, we used Camtasia Studio software to combine the cell phone recordings and video recordings into a single digital file per participant. Those videos were then coded by two research assistants (one who was a proctor) to create a Microsoft Excel file detailing all tasks for all users. That file included whether the task was completed, time on task, the number of errors for the task (defined as any activity that led the participant down a path that could not lead to success).

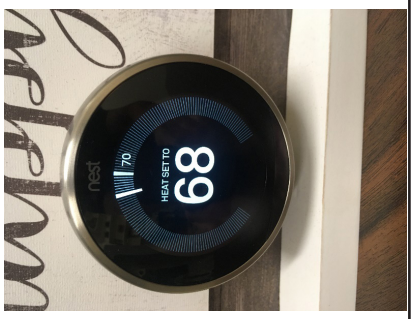
RESULTS

Identification Tasks

When asked to identify 6 devices in the room, participants only struggled to regularly identify the Hello Doorbell, Smart thermostat, and the Nest Hub Max. The Hello Doorbell was occasionally misidentified as the door lock (6 times) and once mistaken for the thermostat. The smart thermostat was misidentified as the doorbell 4 times. The Nest Hub Max was misidentified as the thermostat 4 times and as the security camera 3 times, but was occasionally not identified at all, with participants reporting they were looking for a “small cylindrical or square device”. When asked what these devices could do, participant 7 compared the Nest Hub Max to an iPad, saying it was “an iPad interface for a Google Home” and “It’s kind of like a tablet but you can use it as a TV as well.”



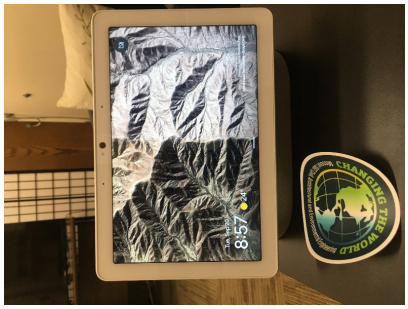
Picture 1: Door Lock



Picture 2:Thermostat

Picture 3: Doorbell

Picture 4:Security Camera



Picture 5:Nest Hub Max

Picture 6: Television

Figure 1: Devices for Identification

Individual Action Tasks

Table 3 lists details about each individual action task; and routine task was classified as having *few or no problems*, *minor problems*, or *major problems*. Each level of problem severity was determined by coding error rates, time on task, TAP comments, and post-test questionnaire comments. That combination of data was critical to determining their classification, because not all errors are the same and the level of user frustration could only be determined through qualitative data. For example, a task which had a relatively high error rate might simply reflect a common error that took little time to resolve and resulted in little user frustration, while a task with a lower error rate might in fact take much longer to complete and result in widespread frustration reflected in user comments. Of the 22 individual action tasks, ten tasks had few or no problems, seven tasks had minor problems, and five tasks had major problems.

Task #	Comp Rate	Average Time [Range] (s)	#Users with more than one	Avg. # of errors	First device	Finished device	Comments
Smart TV	24/24	N/A	0/24	N/A	N/A	N/A	
Nest Hub Max	10/24	N/A	9/24	N/A	N/A	N/A	Misidentified as thermostat (4x) and security camera (3x)
Doorbell	15/24	N/A	7/24	N/A	N/A	N/A	Misidentified as door lock (6x)
Door Lock	22/24	N/A	2/24	N/A	N/A	N/A	
Thermostat	19/24	N/A	4/24	N/A	N/A	N/A	Misidentified as doorbell (4x)
Security Camera	20/24	N/A	1/24	N/A	N/A	N/A	
1	23/24	47.71 [3-160]	2/24	.46	P(13) V(9) H(2)	V(20) P(3) H(0)	Tried Turning on TV with Home App (3x)
2	17/24	49.46 [5-186]	5/24	.71	V(13) P(8) H(3)	V(17) P(4) H(3)	Voice command issues (6x)
3	24/24	31.55 [4-140]	3/24	.6	H(18) V(4) P(2)	H(18) V(4) P(2)	Played Music on the Hub first (5x)
4	23/24	20.54 [3-80]	0/24	.17	P(23) H(1) V(0)	P(22) H(1) V(1)	
5	24/24	10 [1-75]	3/24	.46	P(14) H(8) V(2)	P(13) H(9) V(2)	Issues with Hub media menu (5x)
6	19/24	55.83 [5-189]	6/24	.82	P(9) P(9) H(6)	V(20) P(3) H(1)	Looked for a way to type chosen artist (12x)
7	0/24	84.12 [0-144]	24/24	2.75	H(20) V(4) P(0)	N/A	Impossible task
8	22/24	36.83 [3-122]	4/24	.74	V(14) H(10) P(0)	V(18) H(6) P(0)	Tried to find on Hub despite being voice-only feature
9	21/24	32 [5-149]	2/22	.64	V(19) H(4) P(1)	V(24) H(0) P(0)	Voice command issues (5x)
10	18/24	49.08 [5-168]	6/24	1.17	V(17) H(7) P(0)	V(20) H(3) P(1)	Voice command issues (6x), accidentally set a personal note (5x),
11	24/24	21.63 [1-72]	2/24	.42	P(12) H(10) V(2)	P(13) H(11) V(0)	Attempted to use voice commands (4x)
12	24/24	15.13 [1-32]	0/24	.14	H(18) V(6) P(0)	H(18) V(6) P(0)	Accidentally controlled both lights at once
13	24/24	12.79 [2-84]	1/24	.25	P(23) H(1) V(0)	P(23) H(1) V(0)	Accidentally controlled both lights at once
14	22/24	26.38 [2-81]	0/24	.29	P(20) H(3) V(1)	P(16) V(5) H(3)	Accidentally controlled both lights at once
15	24/24	29 [4-120]	1/24	.25	P(15) H(5) V(4)	P(14) H(6) V(4)	Accidentally controlled both lights at once
16	22/24	29.88 [3-158]	3/24	.62	V(14) P(9) H(1)	V(18) P(5) H(1)	Tried to find on phone despite being voice-only feature
17	24/24	19.17 [5-73]	2/24	.36	P(9) H(9) V(6)	H(13) P(8) V(3)	Voice commands pulled up a YouTube tutorial (4x)
18	23/24	11.71 [1-123]	1/24	.17	H(15) P(7) V(2)	H(16) P(8) V(0)	
19	23/24	13.58 [5-47]	1/24	.21	P(23) V(1) H(0)	P(23) V(1) H(0)	Opened doorbell menu or camera (4x)
20	24/24	16.58 [5-45]	2/24	.38	H(21) V(3) P(0)	H(21) V(3) P(0)	Incorrect voice commands (4x)
21	23/24	7.09 [2-15]	1/24	.13	H(12) V(6) P(5)	H(13) V(5) P(5)	
22	23/24	6.57 [1-50]	2/24	.09	H(16) P(6) V(2)	H(17) P(6) V(1)	
Wakeup	N/A	440.13 [248-688]	24/24	5.3	N/A	N/A	
Movie Time	N/A	321.19 [121-600]	8/22**	2	N/A	N/A	Far fewer mistakes than first routine

Table 3: Task completion rate, average time, errors, devices use, and comments.
***Routine 2 has two users where the phone screencap cut off*

Few or no problems

The 10 tasks with few or no problems included:

- changing the volume of the TV using the Google Home phone app (Task 4)
- playing the next song using any method (Task 5)
- determining how many lamps could be controlled in the room (Task 11)
- turning on a lamp with the Nest Hub (Task 12)
- turning on a lamp with the Google Home App (Task 13)
- speaking through the doorbell (Task 18)
- locking the Smart Door Lock with the phone (Task 19)
- accessing the security camera feed with the Nest Hub (Task 20)
- checking the current temperature of the thermostat (Task 21)
- altering the current temperature of the thermostat (Task 22)

When using the Google Home application most of these tasks were completed with only 2 or 3 taps from the main menu using large, identifiable buttons. As a result, these tasks were usually completed quickly and with few errors and user comments concerning these tasks were minimal. Even the one of these with the highest error rate of .45 errors per participant (the "play the next song" task) had fairly benign errors, with the most common being accidentally leaving the menu to control the Smart TV while using the Google Home app.

Minor problems

We considered 7 tasks as presenting "minor" problems. These tasks included:

- turning on the TV (Task 1)
- starting Netflix on the TV (Task 2)
- playing music on the TV through the Nest Hub (Task 3)
- setting the front lamp brightness to 75% and the table lamp brightness to 85% (Task 14)
- turning the front lamp green the table lamp orange (Task 15)
- setting the lamps to turn off in 5 minutes (Task 16)
- accessing the live video from the doorbell (Task 17)

Turning on the TV had a 96% completion rate and caused an average of only .46 errors per participant, yet participants often had to switch methods. Thirteen participants initially tried to complete this task using the Google Home App but only 3 actually completed it using the app, while 20 participants complete this task using their voice despite only 9 trying voice commands as the first method of control. Starting Netflix on the TV had a 71% completion rate and caused an average of .71 errors per participant, with 6 errors being related to the use of voice commands. One participant wanted a virtual remote on the phone to control the TV for this task, a feature that does exist but they couldn't find in the app. Playing music on the TV through the Nest Hub had a 100% completion rate, but caused an average of .6 errors per participant, with 5 participants playing music through the Hub first and a some having issues casting that music to the TV or having difficulty getting out of the Nest Hub's media menu.

Adjusting the brightness of the individual lamps had a 92% completion rate and caused 5 errors, all of which were participants changing both lamps' colors at the same time, with 5 participants saying they couldn't find controls for the individual lights. Changing the color of the lights had a 100% completion rate and caused 3 errors, all of which were participants changing both lights at the same time. Once they realized their mistake participants on these tasks found the individual light controls quite easily and promptly finished the task. Setting the lights to turn off in 5 minutes had a 92% completion rate and caused an average of .62 errors per participant, usually double tapping or tap and holding the lights power button on the Home App. Participants said they were looking for "some kind of timer" in the Home App light menu or the Nest hub light menu. This task could only be completed using voice commands, which some participants used immediately. Most participants who started with a different method of control eventually came to use voice commands to complete the task, but these participants often performed 2 or 3 errors first while attempting to use the Nest Hub or home app. Overall participants had few issues with adjusting or turning the lights on or off on either the Nest Hub or the Google Home app. However, there was confusion when trying to control one light instead of both lights and with not knowing that light timers can only be created through voice commands.

Accessing the live video from the doorbell had a 100% completion rate but with one notable type of error. Four users attempted to complete this task by using voice commands. This method caused the Nest Hub to perform a YouTube search for installation tutorial videos for the Nest Doorbell.

Major problems

We considered 5 tasks as presenting "Major" problems. These tasks included the following:

- playing participants favorite artist on the TV (Task 6)
- removing weather information from the hub home display (Task 7)
- attempting to set an alarm using the Nest Hub (Task 8)
- translating a phrase to Spanish using the nest hub (Task 9)
- creating a family nest hub note for a specific time (Task 10)

Asking participants to play their favorite artist's music from the TV resulted in a 79% completion rate and caused an average of .82 errors per participant, with 5 participants looking through the Nest Hub's music application, 4 looking through the Home App's menus, 3 participants looking through various other Nest Hub Menus, and 3 incorrectly using voice commands. Participants who did not use voice commands at the start of this task spent a great deal of time swiping through various menus, in particular the Hub Media menu, looking for a way to play a specific song or artist. Four of these participants asked if there was some kind of search bar they could use.

Removing the weather information from the Nest Hub display had a 0% completion rate. While technically possible at the outset of

this study, the setting used to complete this task was difficult to find and was eventually removed from the user interface entirely by an update. Even after its removal, few participants navigated to the menu where the setting used to be during their attempts to complete this task. There was an average of 2.75 errors per participant, with 7 participants opening the weather app on the Nest Hub, 7 trying to use voice commands, 6 trying some variation of tapping on the information and 2 opening the home climate controls on the Hub. Seven participants said they were looking for home screen settings and 6 wanted to be able to just tap and remove the weather info.

Attempting to create an alarm on the Nest Hub for 5 minutes in the future had a 92% completion rate and caused an average of .74 errors per participant. Participants were told to only use the touch screen of the Nest Hub for this task, but many resorted to voice commands after being unable to find the option to create an alarm using the Hub's user interface. Participants said they were looking for some kind of clock, alarm, or time feature. Generally speaking, the Nest Hub was difficult to use and caused an inordinate amount of frustration among participants and major usability issues.

Translating a phrase into Spanish had a 92% completion rate and caused an average of .64 errors per participants, with 3 participants incorrectly phrasing the voice commands, 2 asking the hub if it could translate instead of instructing it to do so, 2 looking through the various hub menus and 2 checking the Google Home App. Participants also said they wanted somewhere to type a question and noted an example tile under one of the Hub Menus, but that tile was not helpful for completing the task. These recommender tiles were present during a few of the tests, but when clicked only provided examples of translations of specific phrases into pre-chosen languages.

Finally, creating a family note on the nest hub had a 75% completion rate and caused an average of 1.17 errors per participant, with 6 participants incorrectly phrasing the voice command and 5 setting a personal note instead of a family note. Two participants tried to find an option in the Hub menus to complete this task as well.

Complex routines

For the last two tasks participants were asked to complete were the creation of two "routines": action scripts that allow for multiple actions to occur simultaneously or sequentially with a single command or button press. The two routines featured 8 and 6 individual tasks respectively (Table 2). Two of those tasks were common to both routines. The tasks shared between the two routines, changing the lamp color and changing the lamp brightness, were a common source of errors and frustration. Twelve participants found it difficult to control the lights during the creation of the first routine, and some failed to implement those tasks at all. Common comments included, "I can see the lights but not how to change them" (this was in a sub-menu) and "I wish there was just a button where you can customize routines." Predictably, the routines were two of the most difficult tasks to complete correctly. A variety of errors occurred, mostly because of user inability to correctly navigate the interface and to control minor variables such as light color.

Post-Test Questionnaire Results

Table 4 below shows averages for each of the quantitative questions contained in the post-test questionnaire, where 1=Strongly Disagree and 5=Strongly Agree. Not surprisingly, only a third of participants though creating routines was easy, whereas approximately half of them thought other processes and devices were easy to use. Somewhat surprisingly 70% of the participants still had a high opinion of SHT and only a small number of them doubted their ability to learn to use SHT quickly.

Prompt	Number (Percent) of Respondents to Agree or Strongly Agree
I found it easy to connect to the devices used in this study using the Google Home cell phone app.	12 (50.0%)
I found it easy to connect to devices using the Nest Hub.	12 (50.0%)
I found it easy to control devices using the Google Home cell phone app.	13 (54.1%)
I found it easy to control devices using the Nest Hub.	13 (54.1%)
I found it easy to link multiple devices in routines.	8 (33.3%)
I have a better opinion of smart home devices than I did before this study.	17 (70.8%)
I believe it would take a long time for me to learn to use this technology.	5 (20.8%)

Table 4: Post-test Questionnaire Results

Usability Issues Across Tasks

Several themes emerged from this research. First, most of the tasks, though often confusing at first, can be completed in a relatively short amount of time. Average times for individual action tasks were all under a minute, except task 7 which could not be completed (Table 3). Small errors do tend to be pervasive when completing the tasks but the intuitiveness of this generation of SHT is vastly superior to the equipment we first started working with in 2017. Yet, the maximum time spent by a participant (Table 3) was often an order-of-magnitude higher than the average. This suggested while most people quickly deal with minor errors to complete a new smart home task, some get confused, lost, or start down the wrong path and take much longer to finish (or do not finish). This may be why participants reported better opinions of SHT and believed they could learn it quickly in spite of not always reporting it was easy.

Second, errors in using the equipment were varied, but tended to center on interface confusion. Numerous small errors occurred during most of the tests, but most of those errors were not fatal for the task at hand. Still, confusion concerning which interface to use (phone, hub, voice) was rampant. As stated earlier, many of the tasks can be completed either by using voice commands, the Nest Hub Max, or the Google Home app on the cell phone. However, some tasks can only be completed using one of those methods. Test participants commented repeatedly on this confusion and often chose either the wrong method or a more difficult method than was required. For example, something as simple as turning on the television could be completed easily with a voice command but could not be completed using the cell phone app, while more complex tasks such as creating a routine to control multiple devices can only be accomplished using the cell phone app. Thus, as users struggled to find the appropriate method for each task, their confidence eroded over time. They found it frustrating that they could not simply choose a method of interaction and stick with it. This seems a legitimate complaint, and one that should be addressed. When multiple methods of interaction are available, users assume that their choice of method is based on preference. However, as we have shown, that is not always the case, and, like the participants, we cannot identify a compelling reason for limiting the methods (other than safety in the case of the door lock).

In general, users defaulted to voice commands in their confusion, but that too proved perilous at times. The AI interface within the Nest Hub often requires very specific wording and phrasing to be effective. Therefore, a poor choice of words or poor diction can often result in failure, even though a voice command should be able to complete many of the tasks. For example, devices must be named when they are added and must be called by their proper name to be controlled effectively. So, a command of "turn on the lamp" may fail, while a command of "turn on the couch lamp" would be successful. Again, most users were able to overcome this setback with time, but the initial confusion was frustrating for them.

Having failed to accomplish the task with a voice command, many users turned to the Nest Hub Max and its visual interface. That, however, proved equally confusing. It should be noted that this is the first version of the Nest Hub Max, so some "bugs" are to be expected. Having said that, visual navigation of features on the Hub screen proved to be confusing and, in some cases, unusable. There is no clear navigational system from the home screen and swiping in different directions yields different results. The lack of a clear navigational system led to additional confusion, frustration, and loss of time. In addition, making even small changes to the Hub display proved exceedingly difficult. Simply removing the local weather display from the home screen proved impossible

for every test participant (even before the aforementioned update made it truly impossible) and setting an alarm on the Hub proved to more difficult than it should be. And, because the Hub has a built-in speaker, asking participants to play music through the television often resulted in music being played through the Hub. In general, the Hub proved to be the most difficult interface for accomplishing any of the tasks, and many users attempted to use it only when forced to after their initial attempts. One user referred to the Hub as, "the dumbest thing in the room." Most of their issues were focused on the navigational issues associated with the touch screen.

Third, the Google Home app on the cell phone proved to be a much more intuitive interface than the Hub. There were some navigation issues with the app, such as confusion among users as to how to control individual lights as opposed to all lights, but most errors that occurred using the app centered on navigational confusion that improved as the test progressed. In general, the app was greatly preferred to the Hub, and to voice commands for more complicated tasks. Failures of diction, phrasing, and capabilities with voice commands led to increased use of the phone app as the test moved on. In some cases, participants reverted to the phone app even after being told to use the Hub.

Fourth, more complex tasks resulted in more errors. This was somewhat to be expected, but there was a marked difference in both time on task and error numbers for tasks that involved manipulating devices as opposed to simply activating them (e.g., turning on a lamp versus turning a lamp green). This was especially true when attempting to control multiple devices with routines. It is true that there is a steeper learning curve to controlling multiple devices, but the routine tasks proved to be the most difficult tasks in the test other than those associated with manipulating the Hub display.

RECOMMENDATIONS AND CONCLUSIONS

Comments from test participants revealed that some improvements can be suggested for both the devices and the interfaces:

- Seven participants (29%) mentioned that they would like to see a search bar to help with locating device features and methods of control.
- Thirteen participants (54%) said that they would like more automated controls for creating routines.
- Eighteen participants (75%) indicated that they would like to see the touch screen interface of the Nest Hub Max redesigned.
- Eight participants (33%) said that they would like to see a tutorial added to the interfaces.
- Seven participants (29%) requested better consistency between user interfaces between the Hub and the Google Home app.

Having said that, participants were generally impressed with the capabilities of the SHT devices. They were especially impressed with the ability of the routines to control multiple devices and the ease of activating individual devices. Finally, users were impressed with the voice activation features for both devices and routines, even if they were somewhat "picky" when it came to language and diction. Post-test comments revealed that the most frustrating aspects of the equipment were a lack of feedback when tasks were not completed, a lack of clarity in the cell phone and Hub interfaces, and a lack of help with errors.

This study also generated practical insight for future SHT research. Studying smart home devices in the controlled environment of the lab allowed us to determine what functions would be tested and to collect and compare data such as completion and error rates as well as the time it took participants to those tasks. The number of devices we had in the lab revealed some points for future researchers to consider when developing their own studies. We found that in setups involving multiple devices such as ours it is essential to have dedicated network hardware for the devices to be connected to. Even with this dedicated hardware, test proctors should be prepared to handle sluggish or potentially unresponsive devices as happened during some of our trials. It is also essential to disable any auto-updating services that may be included on the devices to maintain consistency across multiple trials that may take place over a period of weeks or months. This technology, although functional, is a still moving object. Like many current technologies it changes over time with updates (even though the hardware does not) and more devices equals more problems. While a household with only a smart voice assistant and a television may experience few technical issues, integrated multi-device household systems are more prone to inter-device issues. This is especially true of devices that rely of different interfaces or are manufactured by different companies. And, although updates solve issues, they can also exacerbate issues between devices from different manufactures and different apps.

Even with auto-updates, a laboratory setting offers much more environmental control that studies in the wild, which rely on existing technologies, setup, and physical space. Conversely, the living-room environment of our laboratory made the tasks and interactions more meaningful and understandable to the participants, and more ecologically valid in general. That is, it's possible to line all the devices up in a row and have participants perform tasks with them. It's also possible to task participants with making the door unlock every time one turns down the temperature. However, neither of those are how smart devices play out in real homes. Therefore, we believe studies like ours show the best of both worlds – laboratory control and an ecologically real environment.

Overall, despite the numerous errors and interface confusion, it must be said that this generation of SHT is vastly superior in terms of usability to the last. The Nest Hub Max is in obvious need of revision, but it is also the newest of the devices. Users were, in general, more satisfied with the equipment than they have been in our others' studies with previous generations of SHTs. Having said that, their comments and test results also support the notion that many of them are still trial adopters as identified by Wolverton and Cenfetelli (2019). They are interested in SHT and impressed with its capabilities, but quickly become disillusioned with difficult use and question whether its benefits outweigh the costs associated with learning to operate/troubleshoot it. It remains to be seen if SHT devices and interfaces will continue to improve to a point where these many trial adopters will become true adopters.

APPENDIX A

SCREENING QUESTIONS

1. Do you own or have you ever lived in a home with multiple smart home devices?
2. Have you ever connected smart home devices for

someone else?

3. Are you comfortable using cell phone apps?
4. Have you ever used Amazon's Echo or Google's Nest Hub?
5. Are you currently between the ages of 18 and 23?

APPENDIX B

PRE-TEST QUESTIONNAIRE

Name:

Date:

Thank you for taking the time to participate in our usability test. Before we begin, we'd like to ask you a few questions so that we will have more information about the technology that you currently use.

1. What types of electronic devices do you currently use? (please circle all that apply)
    a. Cell phone
    b. Computer systems
    c. iPod
    d. Gaming systems (Xbox, PlayStation)
    e. Wearable devices and Bluetooth devices
    f. Smart Watch
    g. Smart TV
    h. Television devices such as Roku, Firestick, etc.
    i. Other:
2. What are your primary purposes for using electronic devices?
3. What phone apps (if any) do you most commonly use?
4. What benefits do you think you might gain from using smart home technology?
5. What are the primary frustrations that you have (if any) with the current electronic devices that you use?
6. Have you ever used Amazon's Echo or Google's Nest Hub?
7. Are you currently between the ages of 18 and 23?
8. What's your gender?
9. What's your age?
10. What race/ethnicity do you identify as?
11. What's your major?

APPENDIX C

PROCTOR CHECKLIST/SCRIPT

1. Read the introduction script (see below).

"Thank you for coming in today. My name is [name]. Your participation will help us learn a lot about smart home technology and how it can be improved. It's important that you understand that there are no wrong answers, decisions, or implementations. We are testing how easily and by what methods people can use this equipment, so if you feel you're not able to accomplish anything that tells us that the equipment is difficult to use. So, feel free to make your own decisions and experiment with options.

Today, you will be working with smart home technology—most of which is manufactured by Google. First, we'll tell you what's in the room. Then, we'll ask you to identify those items and what you may think about them now. Finally, we will ask you to perform a series of tasks to see how efficiently the equipment responds to your needs. We'd also like you to talk to us as you work through the test. This will help us to understand how you are experiencing the equipment.

After the test is complete, we'll ask you some questions about your experience so that we can gain valuable information. We'd also like you to talk to us and share your thoughts and feelings as you move through those tasks so we can better understand what you are experiencing."

2. Continue to encourage thinking aloud during the test.

3. Offer assistance only if the test reaches a standstill or participant asks questions.

APPENDIX D
Post-Test Questionnaire

Name:

Date:

		N/A	Strongly Disagree (1)			Strongly Agree (5)	
	Question		1	2	3	4	5
1	I found it easy to connect to the devices used in this study using the Google Home cell phone app.						
2	I found it easy to connect to devices using the Nest Hub.						
3	I found it easy to control devices using the Google Home cell phone app.						
4	I found it easy to control devices using the Nest Hub.						
5	I found it easy to link multiple devices in routines.						
6	I have a better opinion of smart home devices than I did before this study.						
7	I believe it would take a long time for me to learn to use this technology.						

General Questions

1. What was the most frustrating thing about using this equipment today?
2. What was the most pleasant surprise you encountered?
3. What suggestions would you have for improving the Google Home App?
4. What suggestions would you have for improving the devices?
5. What suggestions would you have for improving the Nest Hub?

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