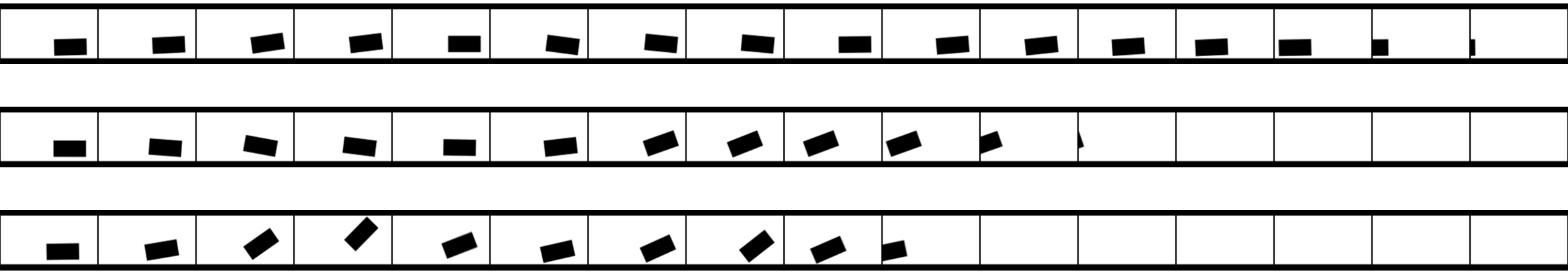
Making a Delivery Robot Streetwise Using Expressive Movement



Master thesis
Integrated Product Design
Delft University of Technology

Master Thesis
MSc. Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology
August 2021

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acknowledgements

I want to thank Zoltan Rusak for being so approachable during my search for a graduation project. Thanks to his suggestions, I came up with the initial brief, and from there, the ball started rolling.

I want to thank my mentor, Jered Vroon, not for giving me the right answers but for helping me find the right questions. I greatly appreciated our open conversations and your focus on the learning experience!

I want to thank my chair, Ruud van Heur, for recognising the projects potential even before I convinced myself of the idea. I am very grateful for your enthusiasm and support throughout the project!

I would like to thank my friends and family for all the times I could count on them! Whether that was by participating in a study or helping me relax and forget about the project with coffee breaks, workouts or video games.

Finally, I would (of course) like to thank my parents for always supporting me throughout my studies and in all other aspects of my life! <3

Sincerely,
Robbie de Groot

executive summary

Last-mile delivery robots intended to operate on the sidewalk still require supervision because they are only semi-autonomous. If left to their own devices, they tend to cause undesired interactions. Our project proposes a design philosophy that can reduce the amount and severity of these interactions, improving the overall acceptance of sidewalk delivery robots.

Our proposed design philosophy uses the power of expressive movement to create delivery robots with a streetwise attitude. Being streetwise means possessing behavioural qualities that allow you to deal with the potential difficulties of an urban environment. Using creative association, we narrowed these qualities down to confidence, pride, calmness, stability and smoothness. A design probe study confirmed that the streetwise qualities can be used to differentiate between desirable and undesirable events.

Next, we propose a methodology to combine our streetwise qualities with movement theories. We verify the efficacy of the method in a 2D movement study. The results suggest that our interpretation of the movement theories is on the right track, but more iterations are necessary to improve the method's reliability.

During our final evaluation, we combine all our findings in a 3D video prototype scenario to confirm if they hold up in a more realistic and relatable context. We showed participants two different versions of this scenario to compare a streetwise delivery robot with a non-streetwise delivery robot in terms of desirability. Both versions turned out to have positives and negatives, but overall, the streetwise robot appeared more favourable.

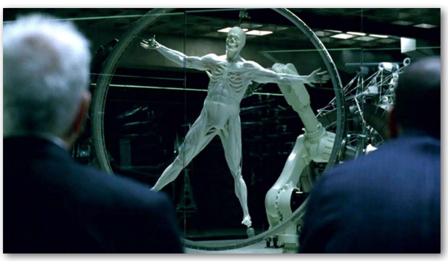
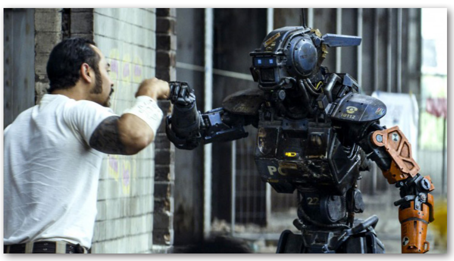
chapter 1

PROJECT

introduction

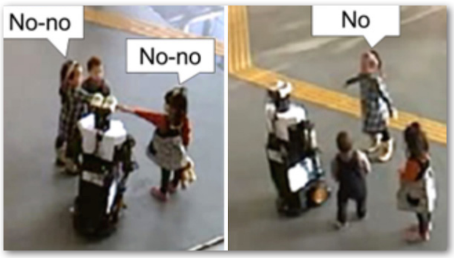
In recent years, last-mile delivery robots have started to see more adoption. While it might not be the case just yet, delivery robots are eventually bound to become more efficient than their human counterparts. Working more consistently, accurately predicting their arrival time, and significantly reducing the chances of human error. With their ability to operate day and night, delivery robots will also be highly available and scalable to accommodate customer demands. While their initial investment may be high, their operation will be cheaper in the long run.

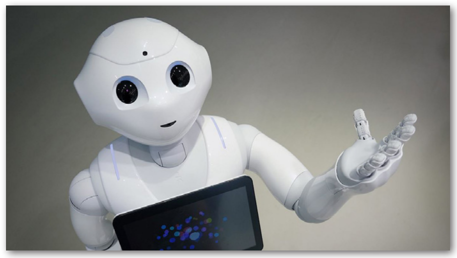
However, delivery robots can only reach their full potential when they can autonomously and confidently execute their deliveries. Right now, that is not yet the case. While more and more delivery robots are starting to roll out, this only happens with near-constant supervision. Sometimes this is done remotely, but more often than not, you will find an (unfortunate) employee walking or cycling behind the robot. The need for this supervision stems partly from the fact that people, and therefore life on the street, are unpredictable. Moreover, if pop culture has taught us anything, people and robots do not always get along. In fact, people can be downright abusive; think TV series like Westworld, movies like Chappie, or video games like Detroit: Become Human.


from left to right: Westworld, Chappie, Detroid: Become Human

Now that robots, in general, are becoming more commonplace in public spaces, real-life examples of this robot abuse are also starting to become more prevalent. An infamous example of this is the tragic fate of HitchBOT, a robot whose purpose was to find out whether or not robots can trust humans. Hitchbot achieved international fame for successfully hitchhiking across the entire length of Canada and most of Germany and the Netherlands, but in its attempt to hitchhike across the United States, it was stripped and decapitated just two weeks into its journey (Dave, 2015). Other noteworthy examples include Robovie, a Japanese mall robot that was beaten up by a group of children (Darling, 2015), and the semi-humanoid service robot Pepper, that reportedly had its fingers ripped off by a visitor during a pilot at a Dutch municipality (J. Vroon, personal communication, January 21, 2021).





from left to right: HitchBOT, Robovie, Pepper

In order to be successful, a delivery robot will need to know how to deal with the difficulties of an urban environment. Among many things, this includes knowing: how to prevent frustration, how to prevent dangerous situations, and how to prevent vandalism or theft. In other words, the robot will need to become *streetwise*.

problem definition

While object recognition, pathfinding, and obstacle avoidance have come a long way, these technologies are still not 100% reliable. Combined with the fact that current delivery robots still move very mechanically and without much smoothness, it should not come as a surprise that delivery robots regularly encounter undesired interactions with the people with whom they share a space. The current solution is to have the robots under near-constant supervision. This solution is, of course, far from ideal as the future potential of delivery robots lies mainly in their ability to operate autonomously.

To reduce the amount and severity of these undesired interactions, we will need to equip delivery robots with the experience, knowledge, skills, attitude, awareness, and resourcefulness necessary to deal with the potential difficulties or dangers of life in an urban environment. In other words, we need to make them streetwise.

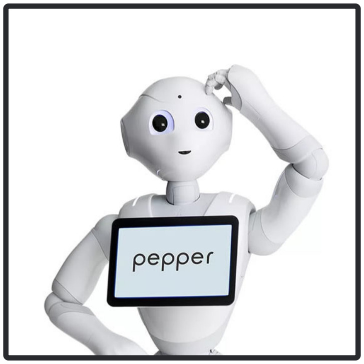
scope

While this project aims to deliver conclusions relevant to the entire realm of delivery robots and the overarching field of human-robot interaction, the project will primarily focus on last-mile delivery robots intended to operate on the sidewalk. Mainly because larger delivery robots, ones intended to traverse roads and cycle lanes, will need to adhere to stricter rules and regulations and therefore offer less design freedom. In addition, these larger robots will be significantly heavier; hence they will be harder to move quickly, which also restricts the freedom when designing movements.

The initial expectation is that expressive behaviour will be one of the functions that allow a robot to become more streetwise. This project defines expressive behaviour as a robot's ability to non-verbally communicate their unobservable internal state and intentions to others around them. In humans, this type of behaviour happens naturally (whether we want it or not) through body language and facial expressions (Morgan, 2012). If we want co-existence with robots to be as intuitive as co-existence with people, we need to equip them with a universally understandable set of expressive behaviours.

Traditional robot design approaches often follow a pragmatic design approach (prioritising the achievement of physical goals as efficiently as possible) or a visual design approach (prioritising the robot's appearance). In neither instance is the robot's expressive quality of movement prioritised. This also seems to be the case in the current design processes of delivery robots.
To set this project apart from the status-quo and to keep it manageable within the allotted time for a graduation project, the solution space will primarily focus on the robot's expressive quality of movement as defined in the movement-centric design approach by Hoffman & Ju (2014).

pragmatic design approach



visual design approach

movement design approach

design goal

Delivery robots have a high value proposition because of their potential to make fully autonomous last-mile deliveries. In most places around the world, however, delivery robots are only allowed to operate on public sidewalks under strict supervision. One of the reasons for this is their tendency to cause undesired interactions.

Research has shown that humans are extremely capable of extracting complex information based on the movement of abstract shapes (Hoffman & Ju, 2014). Besides, humans also tend to assign internal states and intentions to movements of both animate and inanimate objects; a capability usually referred to as Theory of Mind. (Baron-Cohen, 1991).

Based on these observations and on the fact that contemporary delivery robots often display clunky and unnatural movement, one can argue that delivery robots are not conveying their intent as intuitively as they possibly could.

Therefore, the assignment aims to develop an improved way for delivery robots to express their intentions to the people around them. The goal is to reduce the need for supervision, allowing delivery robots to reach their full potential more closely. As mentioned in the scope, this will be achieved through a movement-centric design approach.

Finding the right movements will arguably be the most critical and challenging part of this process since, in some ways, it is as much of an art as a science. For this reason, theories of movement will be analysed methodically in order to explore and define the correct movements in a systematic way.

In addition, end-users will be involved throughout the project in order to validate any findings and assumptions. To make quick iterations and online evaluations possible abstract video animations will be used to create movement prototypes. Finally, the expected solution is a set of recommendations based on the results of a comparative video study.

purpose of research

When driving a car, there are explicit rules that everybody is expected to know and follow. When navigating the sidewalk, on the other hand, rules are implicit. Meaning our behaviour is primarily determined by our social norms and the expectations that come with those. (Fajen, 2018)

Current delivery robots are largely unaware of these implicit rules and lack the expressive capabilities to act upon them. We believe this is a major cause for undesired interactions. Preventing these undesired interactions will require in-depth knowledge of the current behaviour of delivery robots and of the people they encounter.

To gain the necessary knowledge, our research will look at trends in the field of delivery robots to find out what the technology is currently capable of, what its shortcomings are, and what advancements are expected in the near future. This research aims to expose the limitations of current delivery robots caused by their lack of expressive movement.

Secondly, to better understand the implicit rules of the street, the meaning of being streetwise will be explored in the context of delivery robots, including the expressive qualities responsible for making an interaction more (or less) streetwise. This will be useful because knowing the effect of those expressive qualities will allow designers to tweak a delivery robot's behaviour, so they coexist on the sidewalk in harmony with humans, preventing undesired interactions.

Finally, the research will discuss methods for movement-centric design, and it will propose a structured approach to apply these methods in the context of streetwise delivery robots.

chapter 2

research phase

introduction

This chapter contains two types of research and is therefore split up into two sections. The first section contains general background research about the field of delivery robots and it elaborates on the claims made during the introduction and scope.

The second section contains exploratory research and expands upon the problem definition and design goal. This section attempts to answer the research question of what it means for a delivery robot to be streetwise. The findings presented here form the basis for the movement-centric design method introduced in chapter 3.

2.1 background research

In order to become more familiar with the field of delivery robots, this chapter briefly explains our definition of a delivery robot, the different categories of last-mile delivery robots, and the different types of wheel configurations that are currently available. Finally, this section will substantiate the choice for (6-wheeled) delivery robots that operate on the sidewalk.

2.1.1 trends in (delivery) robotics

what is a last-mile delivery robot?

The term "last-mile" is commonly used to describe the final stretch of a delivery process, the step where an item is delivered to its final destination. Besides being a time-consuming endeavour, it is also the most expensive part of the entire shipping process (Dolan, 2021). However, according to a 2018 report by McKinsey & Company, last-mile delivery robots could theoretically cut these costs by up to 40%.

In the context of this project, the term delivery robot is used to describe semi-autonomous ground vehicles that deliver small goods to a consumer's doorstep. Delivery robots come in all shapes and sizes, but they can essentially be divided into two main categories: whether they operate on *the road* (alongside cars) or *the sidewalk* (alongside pedestrians).

Delivery robots intended to operate on the sidewalk are much smaller and lighter than those intended to drive on the road. In addition, their top speed is generally limited to 6 km/h, which roughly equals the average walking speed of a pedestrian. This speed limit is there to increase safety, give robots more thinking time, and give remote teleoperators the chance to intervene (Edwards, 2020).

These circumstances allow sidewalk delivery robots to be classified as Personal Delivery Devices (PDDs) instead of roadworthy Autonomous Vehicles (AVs), which significantly eases their legislative challenges. After all, a delivery robot classified as a vehicle needs to adhere to the same strict rules and regulations imposed on self-driving cars.

Their lenient regulations are part of the reason why sidewalk delivery robots are currently the most prevalent type of delivery robot. The fact that their regulations are lenient is also favourable from a design standpoint, as this allows for more potential design freedom. Additionally, their smaller size and simpler technology allow for lower production costs, giving them an economic advantage. As briefly mentioned during the introduction, these are also the reasons why this project focuses on the "sidewalk delivery robots" category.

types of autonomy

Delivery robots exist with many different levels of control, but there are three main categories. They range from remote-controlled, to semi-autonomous, to fully autonomous. The oldest and most common type used to be the remote-controlled delivery robot, but as electronics have physically scaled-down, and price to performance ratios have gone up, the semi-autonomous delivery robot is now the most common variant.

In this context, semi-autonomous means that the delivery robot can function with limited input from a remote operator. For example, a delivery robot might drive alone on a quiet stretch of sidewalk, but it will signal for help when it encounters a scenario that it does not understand or when it needs to cross a dangerous intersection. Fully autonomous delivery robots are still in their infancy and only operate in well-controlled environments and always under strict supervision (Drones and Personal Delivery Devices, n.d.)

current delivery robots

2-wheeled delivery robots
Delivery robots that use only 2 wheels to move around are a minority, but some companies have managed to make it work. These robots often use a gyroscopic sensor to balance themselves like a Segway, although sometimes additional coaster wheels are added to balance the robot passively. Perhaps the most significant advantage of using just 2 active wheels is that there are fewer parts that can break and that it allows the robot to be small and portable. (e.g. the Piaggio Gita and E-Novia Yape)

4-wheeled delivery robots
Delivery robots that use 4 wheels are a lot more common than delivery robots that use 2 wheels. Their size can range from something as small as an oversized RC car (e.g. Kiwi Bot) to something as large as an industrial copying machine (e.g. Marble).

6-wheeled delivery robots
Delivery robots that use 6 wheels appear to be the most common. This is primarily thanks to the success of the delivery robot from Starship Robotics. Additionally, these robots have an advantage over lesser wheeled robots due to their ability to climb small curbs. They can achieve this by pivoting around their 4 hind wheels, which allows them to stay in contact with the ground throughout the manoeuvre.

Since 6 wheeled delivery robots appear to be the most common, as well as the most capable, this project will focus on this category in particular.

2-wheeled delivery robots

4-wheeled delivery robots

6-wheeled delivery robots

2.2 exploratory research

To better understand the problem definition, this section focuses on capturing the meaning of streetwise: concerning delivery robots, and in context to the environment in which these robots operate. This section will also explore the terminology required to develop expressive movement. This terminology is necessary to achieve the design goal and is acquired from two popular movement theories: the 12 principles of animation and the viewpoints technique. These theories need to be well understood to execute the movement-centric design process, which chapter 3 discusses in more detail.

2.2.1 capturing streetwise

One of the all-encompassing challenges of this project is finding out how to reduce the amount of undesired interactions caused by delivery robots. As mentioned in the introduction, the concept of being streetwise sounds like it could contribute to a solution. However, before this can happen, the concept of being streetwise needs to be operationalised. This means that we do not need an exhaustive understanding of what it means to be streetwise. Instead, we need just enough insight into the variables that define something as being streetwise within the project context to enable us to work with it.

This section starts by defining streetwise based on a combination of dictionary definitions. To better understand the environmental context, a modified version of the free association creativity technique is used. With the help of this technique, we aim to create a list of qualities related to being streetwise. The clustered results of this session produced a total of 5 distinct streetwise qualities. Ultimately, a design probe study is conducted to verify if these streetwise qualities can be used to effectively indicate whether an interaction event that happened on the street was desirable or undesirable.

combined dictionary definition

Based on the definitions taken from Merriam Webster, the Oxford Dictionary, and the American Heritage Dictionary, the word *streetwise* generally has the following meaning:

s*treetwise describes attributes like the experience, knowledge, skills, attitude, awareness and resourcefulness necessary to deal with the potential difficulties or dangers of life in an urban environment*.

Being streetwise is, therefore, about fitting in with your environment, specifically on public streets. It is similar to how adaptation allows animals to survive in the wild. These adaptations can either be physical or behavioural. The same applies to being streetwise. In that case, the physical aspect could be the clothes you wear and the behavioural aspect the amount of distance you try to keep between yourself and strangers.

The eventual goal is to design expressive movements that have a streetwise quality to them. A streetwise assessment model will be created to verify whether this goal has been achieved. If people are then asked to compare the redesigned movements with those of a traditional delivery robot, the assessment model can check if the proposed design changes have been successful.

creative association session

Many design projects are structured to start with a diverging attitude where the goal is to create lots of data, both quickly and effectively. This approach helps create a clear overview of the problem at hand while ensuring that any obvious solutions are out of the way early on in the process. A similar approach is needed to operationalise what it means to be streetwise within the context of the project.

In order to get past typical thinking and to find connections between streetwise qualities and the context of the project, a method was created that is based on the *free association* creativity technique. In free association, you say whatever comes into your mind relative to a word you just wrote or relative to a one- or two-word definition of a problem (Markov, 2019). Instead of using words, the urban environment of Delft served as a visual trigger. While keeping the dictionary definition of streetwise in mind, an initial list of streetwise related keywords was established by observing life on the streets of Delft. Depending on whether the observation felt streetwise or not, associated keywords were then written in one of the opposing categories. The results from this creative association session are on the next page.

Subsequently, similar keywords were clustered into 5 distinct groups. These groups turned out to describe the overarching qualities: **confidence, pride, calmness, stability and smoothness.**

original results		clustered results	
streetwise	**not streetwise**	**streetwise**	**not streetwise**
- confident	- shy	- confident	- shy
- determined	- insecure	- determined	- insecure
- on a mission	- helpless	- on a mission	- helpless
- relaxed	-clueless	- in control	- submissive
- calm	- confused	- calculated	
- unmoved	- stumbling	- deliberate	- unstable
- smooth	- unsteady	- self-aware	- risk averse
- fit / in-shape	- struggling	- teritorial	
- alert but cool	- submissive	- eye contact	- clueless
- in control	- unstable		- confused
- calculated	- overconfident	- unmoved	- stumbling
- stable	- risk averse	- stable	- unsteady
- deliberate	- flamboyant	- risk tolerant	- struggling
- self-aware	- pretentious		
- risk tolerant		- deductive	- overconfident
- dark colours			- flamboyant
- unsaturated colours		- dark colours	- pretentious
- maintaining eye contact		- unsaturated colours	
- deductive		- relaxed	
- teritorial		- calm	
		- smooth / effortless	
		- fit / in-shape	
		- alert but cool	

The initial expectation was that to create a streetwise experience, the qualities that make an experience more streetwise would need to be maximised, and the qualities that make an experience less streetwise should be avoided. However, upon closer inspection, it made more sense to represent the streetwise qualities on a spectrum.

As mentioned earlier, being streetwise is about fitting in, and fitting in can be a complicated balancing act. For example, to fit in with a group, it is generally a good idea to like the same things as the group. However, there is a catch. If you like everything that the group likes and hate everything the group hates, you will lose your identity and everything that makes you unique and interesting. Furthermore, if you do the complete opposite, liking everything the group hates and hating everything they like, it goes without saying things will go even worse.

The same analogy applies to the qualities that make something streetwise. The streetwise qualities can either be expressed too much or too little. The assumption is that to design movements that are streetwise, a balance between the extreme ends of these qualities will need to be found. The question that was asked to define this spectrum was: what would happen if you have “too much” or “too little” of the overarching streetwise qualities? The question was answered with the help of dictionary definitions and synonyms.

Since broad terms are used to describe the overarching streetwise qualities, these terms run the risk of being ambiguous. Because the streetwise quality description cards will be used to make a streetwise assessment model, the definitions of the overarching streetwise qualities must be unequivocally understood. This is important to ensure everybody is on the same page when the streetwise assessment model is used during a study.

Uncertain

a feeling of uncertainty or lack of conviction; unconvinced of what one believes or says.

- risk-averse
- self-conscious
- indecisive
- confused
- insecure
- shy

Confident

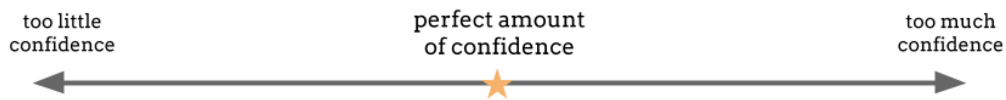
a feeling of self-assurance arising from an appreciation of one's own abilities or qualities.

- risk-tolerant
- self-aware
- courageous
- determined
- optimistic
- bold

Overconfident

a confidence that is not justified; having too much confidence in one's own abilities or judgment.

- presuming
- overbearing
- overoptimistic
- impulsive
- foolhardy
- ignorant



Self-deprecating

to make yourself, your abilities, or your achievements seem less important; to undervalue oneself

- overly humble
- submissive
- undervalued
- embarrassed
- insignificant
- unnoticeable

Modest

behaving so as to avoid indecency, especially to avoid attracting attention

- sober
- discreet
- unobtrusive
- authentic
- sincere
- unsaturated

Arrogant

showing excessive self-satisfaction in one's abilities; presenting yourself as being more important than you are

- smug
- swagger
- presumptuous
- condescending
- attention seeking
- flamboyant

too little pride — perfect amount of pride — too much pride

Anxious

feeling or showing worry, nervousness, or unease about something with an uncertain outcome.

- worried
- concerned
- uneasy
- distressed
- on edge

Relaxed

the state or quality of being free from agitation or strong emotion, not easily worried or excited.

- calm
- carefree
- unconcerned
- cool-headed
- nonchalant

Unconcerned

showing a lack of worry or interest, especially when this is surprising or callous.

- apathetic
- indifferent
- uninterested
- detached
- bored

too little calmness — perfect amount of calmness — too much calmness

Unstable

likely to give way. likely to change or fail; not firmly established.

- shaky
- unreliable
- inconsistent
- reckless
- unpredictable

Reliable

not likely to give way or overturn; firmly fixed. sane and sensible; not easily upset or disturbed.

- sturdy
- trustworthy
- coherent
- well founded
- reasonable

Inflexible

unwilling to change or compromise. not able to be changed or adapted to particular circumstances.

- rigid
- stubborn
- unadaptable
- single-minded
- uncompromising

too little stability — perfect amount of stability — too much stability

Awkward

causing difficulty or feelings of embarrassment and inconvenience; being hard to do or deal with

- struggling
- cumbersome
- uncoordinated
- inappropriate
- clumsy

Effortless

(appearing to) require no physical or mental exertion. To achieve something with admirable ease.

- with ease
- flowing
- smooth
- graceful
- natural

Uncanny

strange or mysterious, especially in an unsettling way.

- odd
- eerie
- creepy
- unnatural
- abnormal

too little smoothness — perfect amount of smoothness — too much smoothness

2.2.2 design probe study

introduction

To find out whether the envisioned streetwise qualities are effective at describing streetwise behaviour and to put that behaviour into a relatable context, a design probe study was set up. A *design probe* is a research method that can be used to better understand the everyday challenges, goals, and needs of a target group (Hillenbrand, 2019). Since this method allows participants to capture their behaviour themselves, it generates largely unbiased insights from their perspective. This aspect makes design probes particularly useful to gain some early inspiration in a design process.

The design probe study attempts to answer the following research question:
What role do the chosen streetwise qualities play in differentiating between desirable and undesirable interaction events in a public space?

By asking participants to keep a daily diary of noteworthy interaction events and by asking them to rate these events on the presence of the streetwise qualities, we hope to find a clear distinction between the ratings of desirable and undesirable events. We expect an interaction event that displays “too much” or “too little” of a particular streetwise quality is more likely to be classified as undesirable.

If our hypothesis is correct, that would mean the process could also be reversed. Meaning the qualities could be used as guidelines and design variables when creating a desirable event involving a streetwise delivery robot.

Because of their exploratory character, design probes are generally not recommended if the goal is to answer specific questions. It is therefore essential to properly guide the participants, so they know what is expected of them. For this reason, participants were encouraged to explain and substantiate their answers throughout the entire study.

method

Besides answering the research question, another goal of our method is to collect examples of real-world interaction events that could serve as design inspiration. To better understand the context behind these interactions, we want to encourage participants to tell stories that expose their reasoning.

Research has shown that self-documentation can record context-related experiences as they occur, minimising retrospection (Csikszentmihailyi & Reed 1987, DeLongis et al. 1992, Brown et al. 2000).
Since a design probe is also a self-documentation technique it seems to be an excellent method to achieve our goal. Furthermore, because it is a daily activity, participants know what to expect and are more likely to pay attention throughout the day, increasing credibility.

The design probe study participants were asked to write a short diary entry on an interaction “event” that they witnessed or were part of for 5 consecutive days, at least once a day. The event could be as short as a few seconds or longer. The questionnaire was made using Google Forms and was shared with the participants via email. Participants received a daily reminder around their preferred time, usually around the end of their workday.

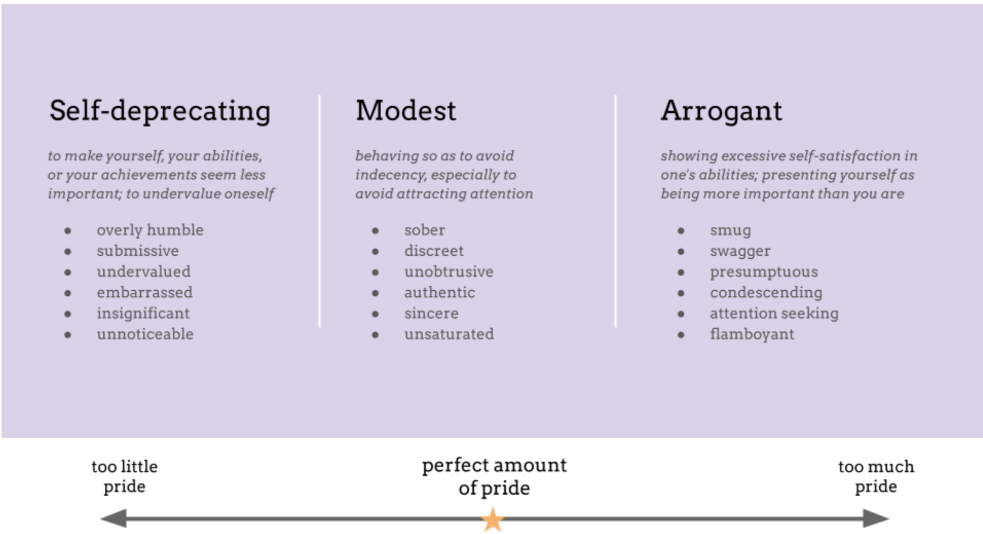
On the first page of the form, participants were asked to describe an event that was noteworthy for being appropriate or inappropriate. It was noted that the event should preferably have happened outside on the streets; for example, an interaction between strangers or acquaintances that occurred on your way to the supermarket. However, due to the social distancing measures in effect during the study, events that did not happen on the street also qualified. These could, for example, have been interactions between people in a household, or these could be conversations that the participant witnessed on TV.

On the second page, participants were presented with 5 cards. Each card described one of the behavioural qualities that are presumed to contribute to the act of being streetwise. Each card asked the participants to rate their described event on the presence of these qualities. To easily compare these answers, a 7-point Likert scale was used. If we take the quality of *confidence* as an example, the scale was divided in such a way that a score of 4 would indicate “the perfect amount” of confidence, whereas a score of 0 or 7 would respectively indicate “too little” or “too much” confidence.

Immediately after participants rated their event on one of the qualities, they were given the (optional) option to leave some feedback if they felt the need to clarify their answer. They were encouraged to mention the synonym on the card that solidified their final answer or to suggest a different synonym that would better describe their event.

In the final question, participants were asked to explain what made their chosen event desirable or undesirable. Based on their answer, the event was categorised as being either desirable, neutral, or undesirable. Participants were encouraged to submit more than one event per day, the option to do so appeared after their submission.

(2/5) Based on the definitions below, how would you rate the amount of "pride" displayed by the party that was most responsible for making the event (in)appropriate? *



1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○

Optional feedback on "pride"

Would you like to clarify your answer? Was a specific synonym responsible for your choice? Or would you have liked to have seen a different synonym to describe your event? Then please leave your explanation and/or suggestions over here.

Your answer

design probe question examples

method evaluation

The design probe study was completed by 10 students in their 20s, of which half had a background in industrial design engineering. The fact that all participants shared a similar age and level of education should not be an issue, as the study explores everyday events that happen outside or in public spaces. In other words, the area of interest deals with shared experiences that are more or less the same for everybody, no matter your background.

Some participants were curious about the meaning of the word streetwise. A detailed definition was purposefully excluded from the assignment's description as it could only cause confusion and was not necessary to answer the questions. Additionally, the assignment's description was kept brief to prevent people from skipping over it.

Finally, among a few participants, there was the misconception that they only had to submit an event if it happened on one of the participation days. While recent events were preferred, as people tend to recall those in more detail, the intended assignment was for the participants to come up with an event every day, no matter what, as events that happened in the past or were experienced by someone else were also allowed. Together with occasional forgetfulness, this explains why participants only submitted about 3.5 events on average over the 5-day course of the design probe study.

The overall approach appeared to be effective as the submitted events were diverse and the results distinct, showing a clear difference between desirable and undesirable events. In the end, two participants even submitted one more event than was required because they witnessed something that just felt like it needed to be added.

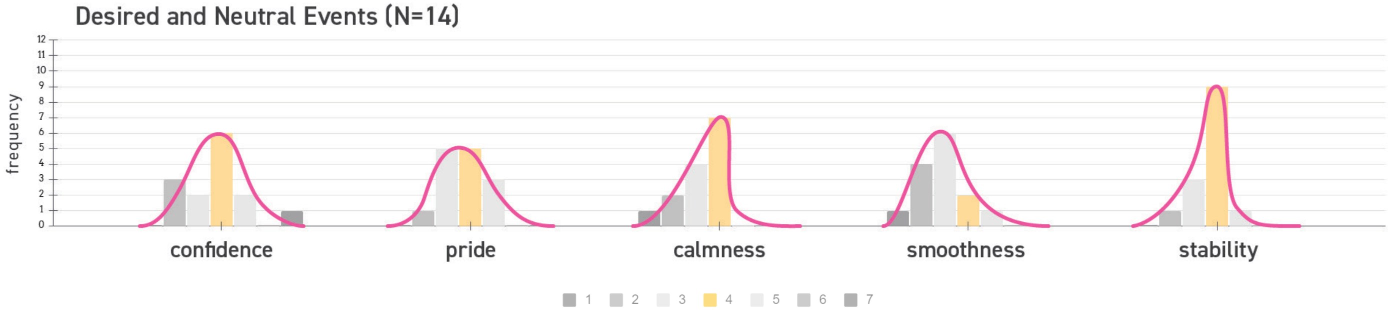
results

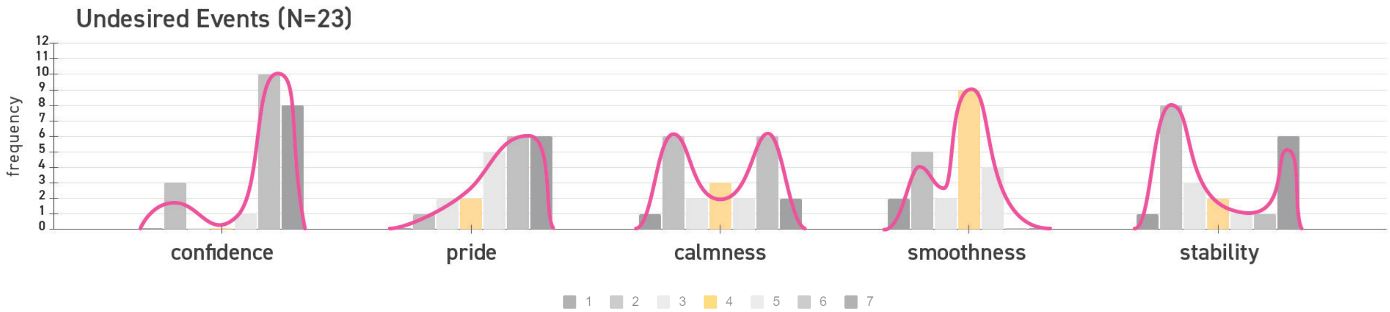
Out of the 37 event submissions, 25 events took place outside; 8 took place inside but in a public area; 2 took place at work, and 1 took place at home. Based on the final question, which asked participants how they experienced their event in terms of desirability, 23 events were classified as undesirable, whereas 9 events were classified as desirable, and 5 events were considered neutral.

As expected, most events were undesirable, presumably, because you are more likely to remember a negative experience than a positive or a neutral one (Baumeister et al., 2001). To compensate for the difference in desirable and undesirable events, desirable and neutral events were combined into one category. If an event involving a delivery robot would be described as neutral, this would also qualify as a positive experience as the goal of preventing an undesirable interaction would still be achieved.

Now that the submissions are categorised, it is possible to analyse the quantitative results. To aid the analysis, we calculate the frequencies of the 7-point Likert scale answers for each streetwise quality. We then visualised these results using grouped bar charts. See the figures below.

To further improve the readability of the results, trendlines were manually added on top of the bar charts. In order to draw conclusions more efficiently, we can *very cautiously* assume that these trendlines hint at what the results could have looked like if the sample size had been larger.





When looking at the "desired and neutral events" category, most scores appear close to the centre or the low end of the Likert scale, with almost no scores above 5 across the board. This results in a distribution that is slightly skewed to the right, especially for the qualities of *calmness*, *stability*, and *smoothness*. The qualities of *confidence* and *pride* show a result that more closely resembles a normal distribution. Perhaps the most significant exception is the low rating for *smoothness*, as it is the only quality in the "desired events" category where the "perfect" score is lower than other scores.

When looking at the "undesired events" category, most scores appear to be on the extreme ends of the spectrum, with scores for qualities of *confidence* and *pride* showing a clear preference for the high end of the Likert scale and with scores for the qualities of *calmness* and *stability* showing a distinct u-shaped distribution. Once more, the most prominent exception is the quality of *smoothness*, as it is the only quality in the "undesired events" category where the "perfect" score of 4 is higher than all other scores within the group.

discussion

One of the goals of the design probe study was to determine how well the streetwise qualities could be used to differentiate between desirable and undesirable events that happened in the real world and on the streets. The expectation was that desirable events would receive ratings close to the centre of the Likert scale, whereas undesirable events were expected to receive scores towards the extreme ends of the Likert scale.

The results tell us that the chosen streetwise qualities can indeed be used to differentiate between desirable and undesirable events. For desirable events, the qualities of *confidence*, *pride*, *calmness* and *stability* show a clear preference for the “perfect” score and for scores around the centre of the Likert scale. These results indicate that these qualities likely have a positive correlation with desirable events.

The only exception appears to be *smoothness*; it appears that events with a less-than-perfect smoothness (i.e. events that are slightly awkward; defined here as causing feelings of embarrassment and inconvenience because someone or something is struggling, uncoordinated or clumsy) can still be desirable or are in fact even more desirable than events with perfect smoothness.

For undesirable events, on the other hand, the qualities of *calmness* and *stability* show the most explicit preference for scores on the extreme ends of the Likert scale. They indicate that both ends of their spectrum can cause an event to be undesirable. For *calmness*, this means being *anxious* or *unconcerned*, and for *stability*, this means being *unstable* or *inflexible*.

In contrast, the qualities of *confidence* and *pride* predominantly focus on the high end of the Likert scale. Therefore, interactions that display *overconfidence* or *arrogance* are more likely to be considered undesirable than events that show *uncertainty* or *self-deprecation*.

The singular score of 7, indicating too much confidence in the desirable events category, appears to be an outlier. The participant likely defaulted to the assumption that higher scores are better, as the accompanying feedback described an event that was explicitly desirable because it had contained a healthy amount of confidence. Therefore it is reasonably safe to assume that the intended answer was a score of 4.

These results matter because they demonstrate that the streetwise qualities can be used to differentiate between desirable and undesirable events. They also indicate the possible intensities with which the qualities are expected to be present in one of these events. Moreover, this means the chosen streetwise qualities could also be used as a streetwise assessment model to design desirable movements.

Suppose the goal is to create a desirable interaction event using our proposed concept of streetwise behaviour. In that case, the high-intensity side of the streetwise qualities (those describing the state of being *overconfident*, *arrogant*, *unconcerned*, *inflexible*, and *uncanny*) should be avoided at all costs. In the results of this study, these scores were never indicative of a desirable event.

Conversely, the low-intensity side of the streetwise qualities appears to be more nuanced. On this side of the spectrum, the most extreme low scores (those describing the state of being *uncertain*, *self-deprecating*, *anxious*, *unstable* and *awkward*) are also unlikely to be associated with desirable events. However, it appears that moderately low scores can still be indicative of a desirable event. Therefore they do not need to be avoided completely.

These results do not explain how to achieve the perfect amount of a certain streetwise quality. However, they demonstrate that the chosen streetwise qualities can theoretically be used as design variables that control the desirability of an interaction event. The results also hint at the direction in which the variables should be adjusted to make an event more desirable. Nevertheless, how this adjustment is achieved remains an iterative process of trial and error, but at least the streetwise qualities can guide this process.

Because the collected events are diverse, the study results likely apply to a broad range of situations. Additionally, great care was taken when designing the streetwise quality cards. Instead of using only two words to describe the ends of the spectrum, definitions and synonyms were added to ensure all participants were on the same page when assessing their events. Nevertheless, to improve generalizability, it is advisable to also conduct the study in different cultures, as those are likely to describe different events, and they might rate these events differently based on differences in their norms and values.

conclusion

As mentioned during the introduction, the goal of the design probe's research question was to determine which role the chosen streetwise qualities play in differentiating between desirable and undesirable interaction events in a public space.

We expected that the chosen streetwise qualities and their spectrums are a good indicator for the desirability of an interaction event. **The results tell us that the streetwise qualities can indeed be used to differentiate between desirable and undesirable events.**

If the goal is to create desirable events using our streetwise qualities, the qualities of *confidence*, *pride*, *calmness,* and *stability* should aim for a "perfect" score. The only exception is *smoothness,* as less-than-perfect *smoothness* correlates most often with desirable events.

The qualities of *calmness* and *stability* should aim to avoid the "extreme" ends of the spectrum, whereas the qualities of *confidence* and *pride* should primarily focus on avoiding the high end of the spectrum. Lastly, "perfect" and "too much" *smoothness* should be avoided as they tend to correlate with undesirable events.

Before the study could commence, we had to develop a philosophy of what it means to be streetwise. This process resulted in the streetwise qualities and the notion that these qualities could be expressed "too much" or "too little". This study is our attempt at using this philosophy to develop a systematic method to assess the desirability of an interaction event. It is novel in that it uses *the concept of being streetwise* as an indicator of the desirability of a public interaction event.

Arguably the most exciting topic for future research is discovering the mechanisms that can be used to achieve *the perfect amount* of a certain streetwise quality. Chapter 4 will look at how to achieve this from an expressive movement standpoint.

Future research should also aim for a larger sample size to validate if the trendlines represent the larger population. In addition, it is advisable to compare the effect that different cultural backgrounds can have on defining when an event is considered desirable.

Finally, it would be interesting to determine why *perfect smoothness* is the only quality that inversely correlates with desirable events. Could it be that *perfect smoothness* is genuinely an undesirable quality? Or is it perhaps our definition that is being misunderstood?

2.2.3 theories of movement

One of the project's main goals is to design expressive movement for a delivery robot. The previous paragraph focused on the "expressive" aspect of this design goal. It defined the streetwise qualities and hinted at the measure in which these qualities need to be expressed. This paragraph looks at the movement aspect of the design goal by briefly discussing two commonly used movement theories. In particular, the 12 principles of animation, introduced by the Disney animators Ollie Johnston and Frank Thomas, and the Viewpoints technique, as defined by directors Anne Bogart and Tina Landau.

These theories were chosen as their associated terminology is by many considered the industry standard when defining movement in projects involving animation or acting. Finally, this chapter will propose some adjustments to the original theories to make them more relevant and practically applicable to the project's delivery robot context.

the original 12 principles of animation

First published in 1981, the 12 principles of animation were based on the work and experience of Disney animators over 50 years. The main goal of the principles was to help new animators achieve more realism and visual interest in their animations. For reference, the original list can be found on the next page.

The original 12 principles of animation

1. Squash and Stretch. Characters and objects should squash and stretch with their action, although they do not completely lose their shape.

2. Anticipation. Major action should be telegraphed such as reaching back before throwing an object.

3. Staging. An action should be clear to the audience. For example, the audience should understand the action by only viewing it in silhouette.

4. Straight Ahead Action and Pose to Pose. This principle describes how to draw an action. Drawing straight ahead involves starting to draw and simply continuing until the action is completed. Pose to pose implies that specific poses are desired in an action and are choreographed before the actual animation.

5. Follow Through and Overlapping Action. Actions are not performed in isolation. An animated character exhibits a plan and moves from one action to the next without stopping between.

6. Slow In and Slow Out. The speed of a motion is not the same during the time that it is performed. Action is slower at the beginning and end.

7. Arcs. Move limbs in arcs as opposed to straight up-down and left-right motions.

8. Secondary Action. Create complementary actions that emphasize the main action. For example, a character puts on a coat while walking out the door.

9. Timing. Changes in the number of frames that are between a start and stop determine the speed of the action, thereby increasing the number of frames and decreasing the speed of the action.

10. Exaggeration. Exaggerated action ensures that it is easier to understand the feelings of a character.

11. Solid Drawing. Drawings should look plausible and three-dimensional and twins (symmetrical limbs on a character) should be avoided, since it makes characters look stiff.

12. Appeal. All the characters should be appealing whether one is expected to sympathize with them or despise them.

Summarized by Schulz et al. (2019)

the improved and reordered principles of animation

The use of the word "principle" might deceive the reader into thinking that the 12 principles of animation, and the order in which they are presented, are a universal truth based on scientific facts. In reality, the list was mainly based on the personal experiences and observations of the authors. Therefore, the original list leaves some room for improvement. Based on that notion, renowned animator Hjalti Hjalmarsson suggested some changes during the 2017 Blender conference. To substantiate our choice for this new version, a summary of the reasoning behind these changes is provided below.

Firstly, "straight ahead and pose to pose" has been removed as these terms describe a type of workflow and they are not principles in and of themselves. Similarly, "appeal" is also not a principle but rather a thing to strive for; it has therefore also been removed.

Thirdly, "follow through and overlapping action" are two separate and equally important entities and should be split up. Fourthly, "staging" is one of the broadest principles on the list; it touches upon cinematography, directing, and acting choices; for that reason, it can be split up into (at least) two categories, which are: "staging & clarity" and "readability & focus". Fifthly, a better name for "ease in, ease out" would be "spacing" since that is the term used these days by animators in the field.

Finally, the order of the list has been changed so that the principles with the most influence on appeal are higher up on the list.

The improved principles of animation

1. timing and rhythm (4:12) The dimensions of space and time are the canvases of an animator. Unpredictable rhythms are generally more interesting and keep people interested.

2. spacing (7:10) Between every key-frame there is some space that something travels. The further the spacing, the faster something travels. Linear and splined (bezier) are automatic spacing methods.

3. squash AND stretch (9:10) Always keep the volume consistent. Useful when speeding up and slowing down

4. arcs (10:30) If something does not move with an arc it looks rigid and stiff (and weird). Squash and stretch should follow the direction of the arc.

5. anticipation (12:05) Forces should generally come from somewhere (e.g. winding up / coiling a spring). Can be used to give inanimate objects a lot of agency (intent).

6. drag and follow through (13:00) Basically inertia (e.g. dragging a yo-yo sideways while holding the string)

7. asymmetry (14:40) Always present in nature. Can make something more interesting and appealing.

8. overlapping action (15:50) It feels weird when everything moves at the same time. A breakdown pose shows what is leading and what is being delayed. It is less about inertia and more about agency and acting choices.

9. secondary action (17:54) Something unrelated to the main event (e.g. pouring iced-tea or smoking during a conversation). Can be used to complement and emphasize the primary action

10. exaggeration (19:40)
All of the above can be pushed further.

11. consistency (20:28) Stick with your choices and work within those boundaries. People should be able to know if they are still looking at the same thing. As opposed to irregularity and surprise.

12. staging & clarity (21:40) Staging and posing should focus on the audience / viewer. Ideally you should only need a silhouette to tell what something is.

13. readability & focus (23:22) At 24fps you need at least 2 frames to notice something. Waiting longer gives emphasis and allows your audience to catch up. You want to push the readability with respect to the urgency of the scene.

Notes taken from Hjalti Hjalmarsson (2017)

the original Six Viewpoints theory

Initially developed by Mary Overlie, The Six Viewpoints is a study that attempts to establish the base of performance by inquiring into the vocabulary of the basic materials found in the creation of all art (Overlie, 2016). These materials are: space, shape, time, emotion, movement, and story.

the 9 physical viewpoints

For our project, we are mostly interested in the 9 physical viewpoints, as defined by Bogart and Landau. According to them, **viewpoints are a set of names given to specific principles of movement through space and time; these names constitute a language for talking about what happens on stage.** The viewpoints act as points of awareness that a creator can make use of while working. We chose their interpretation for their practical approach as it is in many ways analogous to the principles of animation.

Additionally, the final two paragraphs of The Viewpoints Book eloquently highlight the relevance of viewpoints to our project's goal of designing expressive movement that is natural and organic:

> *"Watch the way animals flock. Watch the way a school of fish shifts direction as if one. Watch people waiting for a bus or train -- when one person leans out to check for the oncoming vehicle, other immediately follow. Watch people on the subway or watching a movie -- when one person shifts weight or angle, there is a ripple reaction that follows from one to another.*
>
> *The ultimate lesson of Viewpoints, might be one of humility. We did not invent a system that the world mirrors. Rather, it is the natural world itself that holds such timeless and consistent patterns of behavior. It is our struggle to name the patterns and then apply them to our art."*

Overview of the 9 physical viewpoints

Viewpoints of Time

- **Tempo**: the rate of speed at which movement occurs
- **Duration**: how long a movement or sequence of movements continues
- **Kinesthetic response**: (the timing of) a spontaneous response to motion which occurs outside of you
- **Repetition**: the repeating of something
    - **internal repetition**: repeating movement within your own body
    - **external repetition**: repeating the shape, gesture, tempo, etc. of something outside of your body

Viewpoints of Space

- **Shape**: the contour of a body
    - consisting of (1) lines, (2) curves or (3) a combination thereof
    - can be (1) stationary or (2) moving
- **Gesture**: movement involving part(s) of a body, basically a shape with a beginning, middle, and end
    - Behavioural gesture: belongs to the concrete world of human behaviour (e.g. pointing or waving)
        - private of public: performed in solitude or with awareness of or proximity to others
    - Expressive gesture: expresses an inner state, emotion, desire, idea, or value (unlikely in the supermarket)
- **Architecture**: the physical environment in which you are working and how awareness of it affects movement
    - can be broken down into: solid mass, texture, light, colour, sound
    - spatial metaphors (e.g. up against the wall, trapped, lost in space)
- **Spatial relationship**: the full range of possible distances between things on stage
- **Topography**: the landscape, the floor pattern, and the design we create in movement through space

Summarized from "The Viewpoints Book: A Practical Guide to Viewpoints and Composition" by Bogart & Landau

chapter 3

DEFINE

introduction

This chapter introduces a method that allows us to design expressive movement that embodies the streetwise qualities proposed in the previous chapter. The method of choice is the movement-centric design approach as described by Hoffman & Ju in their 2014 paper titled:
Designing Robots with Movement in Mind.

As indicated by the title, the paper concerns robots in general. However, Hoffman & Ju do present several specific case studies to support the proposed methodology. These case studies demonstrate how the movement-centric design approach can be successfully applied to a variety of robots.

Since the approach has, to our knowledge, never been explicitly applied to delivery robots, this chapter will highlight the aspects that we deemed most valuable for our project.

movement-centric design

In recent years, the biggest technological hurdles that kept delivery robots from being a reality have been overcome. However, up until now, little attention has been paid to the expressive qualities of delivery robots. These qualities were likely not prioritised earlier because they are considered more of a *desire* than a *necessity*.

This project aims to improve people's acceptance of sidewalk delivery robots by reducing the chances of undesired interactions. We believe that the inability of delivery robots to convey their intent and internal state to the people around them is one of the major causes of these undesired interactions. Therefore, the aim is to alleviate these undesired interactions by designing recommendations that dictate how a delivery robot should ideally behave from an expressive movement standpoint. The movement-centric design approach will help us with that.

design challenges

The movement-centric design approach is summarised into four separate design challenges. Those challenges are: (1) discovering the right movements, (2) implementing the movement, (3) matching form to movement, and (4) validating the design.

Due to the limited scope of this project, the choice was made to focus primarily on the first design challenge. After all, according to Hoffman & Ju, exploring and discovering the right movements for the robot is the core design challenge of their approach. In order to find the right movement, they suggest that the designer considers the use of the robot, its personality, the internal states, and other information it needs to communicate and fit into the human environment. Questions like these should guide the movement that the delivery robot needs to achieve. Chapter 4 will explain this process in more detail.

Once the ideal movements are found, the second design challenge looks at how these movements can be physically achieved, i.e. the design of the mechanical systems needed to support the robots movement requirements. For a delivery robot, this mostly means analysing how any additional degrees of freedom can potentially be added to allow for more expressive movement. Since the exact functioning of the mechanical system is greatly dependent on the exact type of delivery robot and because the project looks at delivery robots in general, a black-box approach is used to circumvent the need for a complex mechanical system.

The third step in the movement-centric design process is designing the robot's overall shape and aesthetics in a way that compliments the chosen movements. This step is also touched upon briefly since it can be an entire project on itself and depends significantly on aspects like branding and the designer's personal preference. Therefore, the choice was made to keep the final design just detailed enough to understand that the context concerns sidewalk delivery robots.

Finally, the fourth design challenge is to validate whether the chosen combination of form and movement has the intended effect. Ideally, a physical prototype of the delivery robot is used in real-world scenario's to see how it measures up to the intended design goals. However, to be able to quickly asses our assumptions, the choice was made to design a digital prototype and to conduct many smaller validation sessions throughout the project instead.

chapter 4

DEVELOP

introduction

In this chapter we propose and demonstrate a methodology to combine our streetwise qualities with movement theories. This method is based on the process of *finding the right movement*, as proposed by Hofman & Ju.

The method start off by exploring critical gestures and degrees of freedom relevant to our delivery robot context. Next, we present a technique to interpret the movement theories that were introduced section 3 of chapter 2. Lastly, we verify the efficacy of the method in a 2D movement study.

Based on these results, te next chapter will combine and presents our findings in a 3D video prototype scenario. This scenarios will be used to conduct our final evaluation study.

critical gestures

Movement and gestures are essential to the coordination and performance of joint activities, where they serve to communicate intentions (Clark, 2005). The first step in designing movement and gestures for a delivery robot is to uncover the opportunities where streetwise movement can be incorporated. During its operation, the interactions a delivery robot encounters are based on a combination of common delivery robot *actions* and the *context* in which these actions occur. Whenever an interaction has a high risk of being undesirable, we call this a *critical gesture*. An example of this would be a delivery robot passing a pedestrian on a narrow sidewalk.

actions

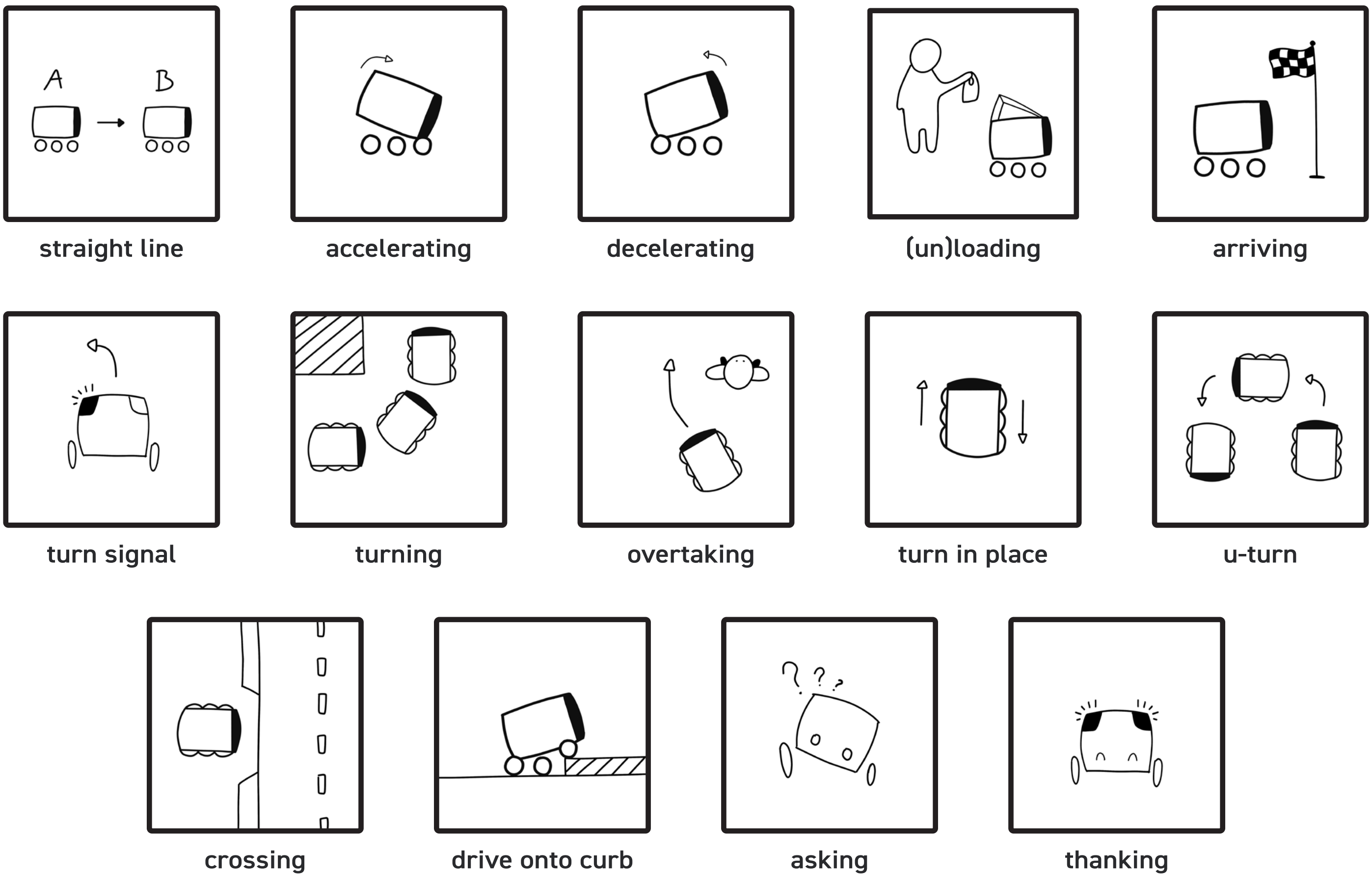
On the next page is a selection of delivery robot actions. The list is non-exhaustive but should sketch a good overview of the most common delivery robot actions.

contexts

The context in which a delivery robot performs its actions can be divided into 4 categories:

1. The type of road
e.g. pavement, bike path, car lane, one-way street
2. The person or object encountered
e.g. children, animals, pedestrians, skaters, cyclists, cars
3. The intent of the person
e.g. to coexist, to play, to annoy, to steal, to vandalise
4. The part of the journey
e.g. charging, waiting, (un)loading, travelling, arriving

common delivery robot actions



To efficiently test our initial assumptions we decided to limit ourselves to actions that can be visualised in 2D. For this reason, we chose to explore the different ways in which a delivery robot can initiate *acceleration* from idle. We call this action the *take-off* gesture. Chapter 5 on the other hand will explore 3D animations that take a more in-depth look at some of the critical gestures.

degrees of freedom exploration

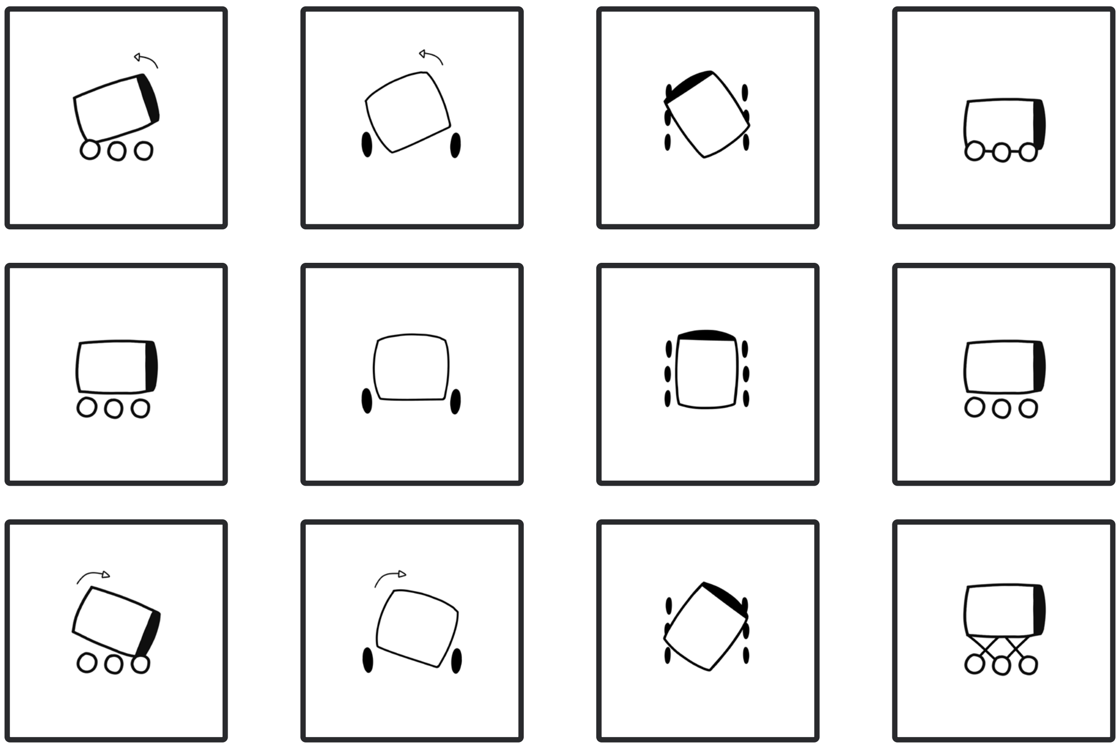
When following the movement-centric design approach, expressive movement that conveys intent becomes the starting point. This means that it is vital to consider the robot's degrees of freedom (DOF) early on in the design process, as the DOF will dictate the types of movement that the robot is physically able to execute.

At first glance, however, additional degrees of freedom that do not directly contribute to a delivery robot's primary goal - physically transporting items from point A to B - might sound like they are adding lots of unnecessary complexity. After all, Einstein is often praised for (allegedly) having said that the best design is the simplest one that works. While that is often true from a durability and costs perspective, the case can be made that adding certain degrees of freedom is a justifiable investment.

Researchers have found that the movement-centric design approach often leads to robots that display formal simplicity while exhibiting their complexity and sophistication primarily through carefully designed movement qualities (Hoffman & Ju, 2014). Furthermore, the ability to express intent and a streetwise attitude through movement might significantly improve pedestrian acceptance with its potential to reduce undesired interactions.

During this project, the following DOF are taken into account.

DOF overview



applying movement theories

Now that we are familiar with the critical gestures and degrees of freedom, we can start to apply the different movement aspects, from the animation principles and viewpoints, to create movement that expresses the streetwise qualities. To do this in a systematic and analytical way, we quantified the importance of the movement aspects with respect to the streetwise qualities. The word "importance" is used here to indicate how much a movement aspect contributes to the expression of a streetwise quality.

To calculate the importance ratings, we need a method to evaluate the future user experience without building a fully functional prototype. According to Weiss et al. (2009), a popular methodology to achieve this, often used in the early stages of Human-Robot Interaction (HRI) research, is the Wizard of Oz (WOz) approach. In a traditional WOz study, a human "wizard" usually manipulates an interface. In HRI research WOz studies, the wizard approach often replaces the response behaviour of an embodied robot.

In our project, the different movement aspects were individually applied during a kind of role-play session. During this session, a small rectangular cardboard box (the prototype) resembled a delivery robot. One person (the wizard) would use their hands to move the box around; the other person (the observer) would then assign a score based on how successful the movement aspect was in expressing the desired streetwise quality.

In our project, the different movement aspects were individually applied during a kind of role-play session. During this session, a small rectangular cardboard box (the prototype) resembled a delivery robot. One person (the

wizard) would use their hands to move the box around; the other person (the observer) would then assign a score based on how successful the movement aspect was in expressing the desired streetwise quality.

In the first column, the 5 streetwise qualities have been listed. To their right, the effect that the corresponding movement aspect has, in trying to achieve the desired streetwise quality, has been given an importance rating between 1 and 5. A score of 1 indicates that the movement aspect had very little influence, and a score of 5 indicates that the movement aspect had a large influence. Alternatively, a score of N indicates that the movement aspect had a negative influence and should therefore be avoided.

Similarly, the effect of the degrees of freedom on achieving the desired streetwise qualities has also been analysed. The results can be seen in the spreadsheet below.

applied movement theories spreadsheet

9 physical viewpoints	tempo	repetiton*	kinesthetic response	duration	shape							architecture	spatial relationship	topography	**Degrees of Freedom**						
12 animation principles	timing & rhythm			spacing	squash & stretch	arcs	anticipation	drag & follow through	overlapping action*	secondary action	consistency	staging & clarity		readability & focus		driving (x-translation)	turning (y-translation)	height (z-translation)	roll (x-rotation)	pitch (y-rotation)	yaw (z-rotation)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		1	2	3	4	5	6
confident	2	4	5	3	N	N	2	1	4	N	5	3	5	2		4	1	3	1	3	5
proud	1	N	4	5	4	1	1	3	N	4	N	5	4	3		4	1	5	1	4	1
relaxed	5	1	1	3	5	5	4	3	4	4	1	2	2	3		1	4	3	2	4	1
reliable	2	5	1	1	N	N	5	1	N	N	5	4	4	5		3	3	3	2	1	N
effortless	N	3	4	N	2	4	2	1	5	1	4	N	N	1		2	2	N	N	N	4

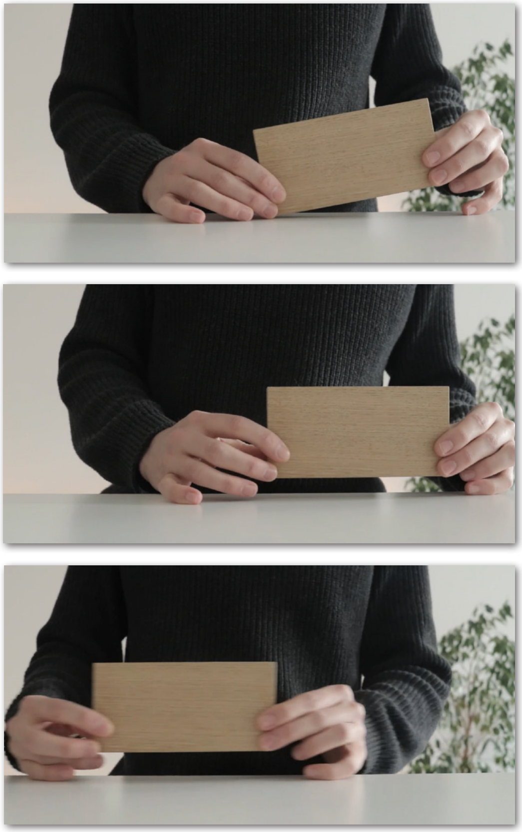
abstract video prototypes

Now that we have established the critical gestures and degrees of freedom relevant for a delivery robot and have applied the movement theories to our streetwise qualities, it is time *to discover the right movement*. As suggested by the movement-centric design approach, we choose to evaluate our initial findings using *abstract video prototypes*.

The purpose of these video prototypes is to demonstrate that it is possible to express the streetwise qualities through movement alone. We deliberately chose to use an abstract shape without any visual reference to delivery robots or anthropomorphism to ensure all behavioural and emotive qualities originate from the movement.

The photographs on the next page give a small preview of the process behind creating the abstract video prototypes. With the help of the "applied movement theories" spreadsheet mentioned earlier, a wooden block was moved around in front of a camera to quickly and intuitively develop many movement concepts. The recordings were then tracked and tweaked using Adobe After Effects. The image below the photographs is a representation of the final result. We will refer to this image as a *video overlay*. How the image was made will be explained later on in this chapter.

video prototype process



video overlay example

2D streetwise movement pilot study

During the streetwise design probe, it became clear that certain qualities can make an event more or less streetwise. The eventual goal is to make a delivery robot convey these qualities through expressive movement. Based on our current findings, we crafted 7 abstract video prototypes. The goal of these initial video prototypes was to represent the streetwise qualities around their perfect intensity, creating an ideal scenario. How the videos and their figures were made is explained in more detail in the section after the pilot study.

The pilot study's purpose was to figure out if participants would associate the correct video prototypes with their intended streetwise quality. To keep the pilot brief, we did not ask participants to rate every video on the presence of all streetwise qualities, as we did during the design probe study. Instead, we only asked which quality they found *most applicable*.

Which quality applies the most? *

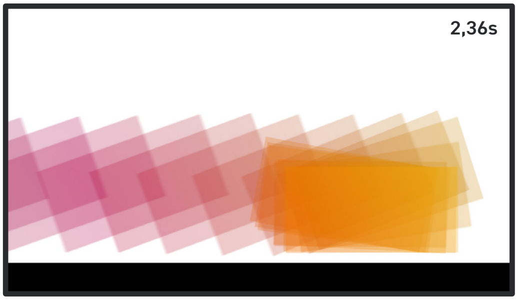
- confident
- hurried
- proud
- relaxed
- effortless

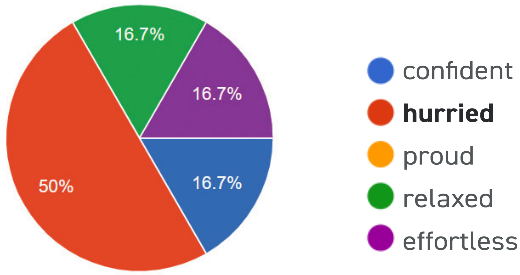
pilot study question example

results

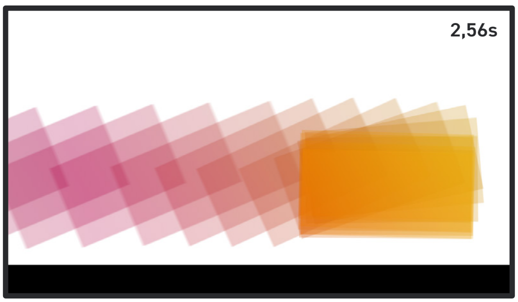
The pilot study was completed by 6 participants. As expected, there was quite some overlap between the attributed qualities, but this is not necessarily a bad thing as long as the intended quality has the majority of the votes.

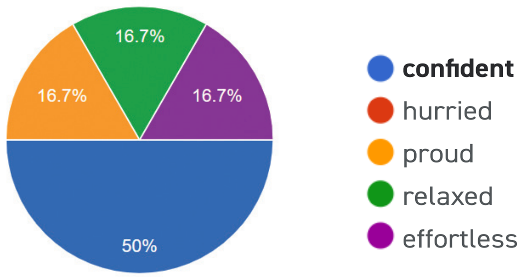
1. confident



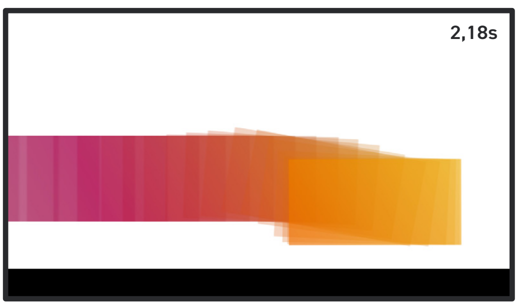


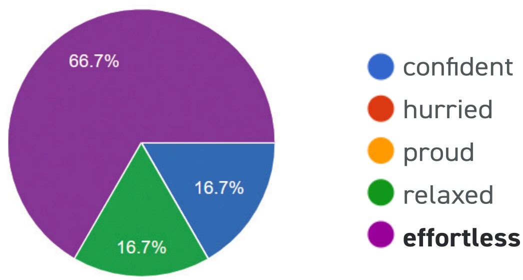
2. confident



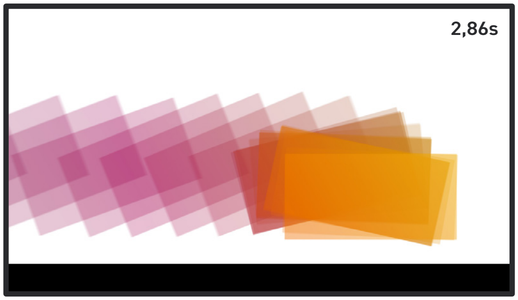


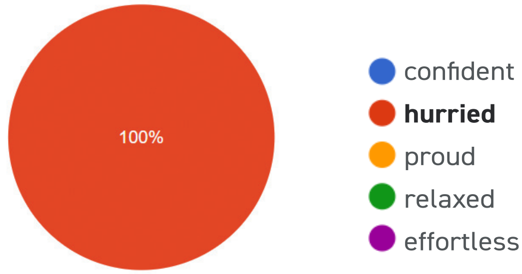
3. effortless



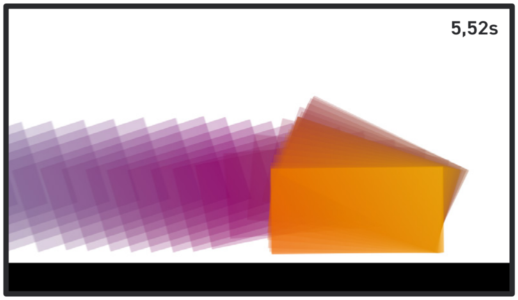


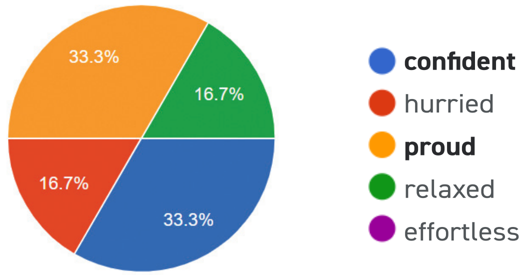
4. hurried



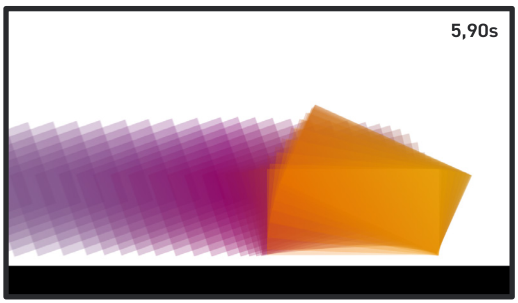


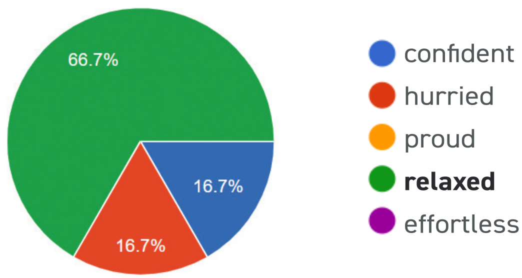
5. proud



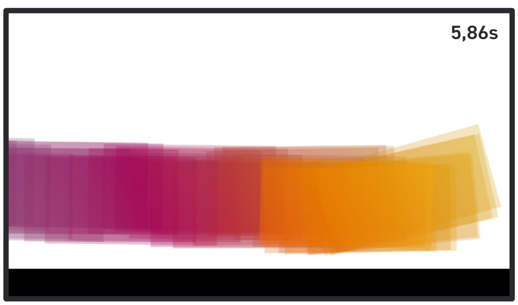


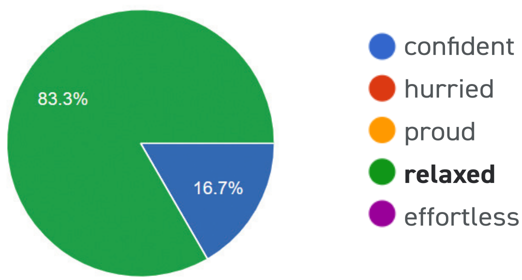
6. proud





7. relaxed





Out of all questions, 4 out of 7 received the intended answer more often than the unintended answers. Out of the remaining questions, one was a tie, and the others received only one intended answer or not a single intended answer.

Question 1 intended to display *confidence*. However, the majority of the participants perceived it as been *hurried*.

Question 2 was a variation of the first one and also intended to display *confidence*. This time, the majority of the participants choose the intended answer.

Question 3 tried to capture the *effortless* quality and succeeded, with 4 out of 6 participants giving the intended answer.

Question 4 was supposed to be *hurried*, which was very clear as all participants chose the intended answer!

Question 5 intended to display *pride*, but the results were a tie between *proud* and *confident*, perhaps unsurprisingly, as both qualities share quite a few similarities.

Question 6 also intended to display *pride*, but none of the participants provided the intended answer! Perhaps this was because the movement was quite a bit slower compared to the movement in question 5.

Finally, question 7 tried to capture the *relaxed* quality and succeeded greatly, with only one participant choosing an unintended answer.

discussion

To prevent the confusion that possibly occurred between questions 1 and 2, and questions 5 and 6, the order in which the questions are shown during the official study should be randomised as previously seen questions can influence how you perceive subsequent questions—a phenomenon known as *question order bias* (Blankenship, 1942).

The shortest video during the pilot lasted only 2 seconds, whereas the longest lasted almost 6 seconds. Speed and acceleration appear to have a significant impact on how the streetwise qualities are perceived. Therefore, the intensity of movement principles such as timing, speed and duration should not deviate too much. The question order bias likely strengthens this effect as these qualities are often relative to each other.

Initially, the duration of all movements was averaged to 4 seconds to prevent speed and acceleration from overshadowing the effects of the other animation principles. However, this adjustment turned out to be too drastic. The new prototype videos lost their liveliness and became too static. To not completely eliminate the effect of duration, we decided only to reduce *the difference* in duration between the longest and shortest videos.

conclusion

Overall the initial results look optimistic. For the definitive movement study, the order of the questions should be randomised, and the difference between a movement's speed and duration should be less than 2 seconds.

2D streetwise movement study

During the pilot study, we wanted to see if we could craft abstract video prototypes that express the streetwise qualities at their "perfect" intensity. Now that we have confirmed that people can quite accurately match these video prototypes with their intended streetwise qualities, we feel confident enough to also analyse the "extreme" intensities. Therefore we made 10 additional video prototypes that represent the "too little" and "too much" intensities on the streetwise quality spectrum.

Additionally, we want to understand any potential overlap between the streetwise qualities (e.g. a movement could be interpreted as both confident and proud or relaxed and effortless). Therefore, we want to collect more nuanced answers during this definitive streetwise movement study. This means we will not ask participants which quality applies the most but instead, we ask them to *rate the intensity* of the qualities for all 15 video prototypes.

This study's research question is: **how effective is our interpretation of the movement theories in creating movement prototypes that express our behavioural streetwise qualities?**

If our assumptions are correct, we expect to see low ratings for low-intensity videos, perfect ratings for perfect-intensity videos and high ratings for high-intensity videos. Ideally, we are also able to tell, purely by looking at the results, which quality the video prototype intended to describe, although we expect this will not be easy since we have already established there can be overlap between the qualities.

method

Based on the pilot study results, we kept the "perfect" intensity video prototypes that worked best and tweaked the ones that were unclear. The new "extreme" video prototypes were once again made with the help of our "applied movement theories" spreadsheet. This time we made sure to limit the difference in speed, acceleration and duration between the different video prototypes (to prevent them from overshadowing the effects of other movement principles).

The questionnaire was once again made using Google Forms. Each movement video was put on a separate page in order to group it with the accompanying questions. Due to a technical limitation, it was impossible to randomise these pages automatically. To alleviate this issue, we manually created 3 versions of the form where the pages were randomised using a random number generator. Participants of the study received a special link that automatically redirected them to one of these forms. Participants were encouraged to submit the form using a smartphone or tablet as a "portrait" screen orientation provided the best overview of the video and questions, preventing excessive scrolling.

On the first page of the questionnaire, participants received a brief introduction to the project. Although the definition of streetwise is unnecessary to answer the questions, we provided a short description as many people asked for it, out of curiosity, during the design probe study. We explained that we explored the influence of 5 behavioural qualities on public interaction events and that based on those results, we crafted 15 abstract movement prototypes that attempt to express those qualities in varying degrees of intensity.

The assignment was to rate every prototype video, using a 5-point Likert scale, on the presence of our 5 streetwise qualities. Participants were assured that there are no right or wrong answers as we are primarily interested in their personal interpretation and intuition. Participants were advised to complete the form within 15 to 20 minutes to prevent overthinking. As can be seen in the example on the next page, the prototype videos could only be identified by a random number.

The final question showed participants the 5 perfect-intensity prototype videos side-by-side. They were then asked which of the movements was, according to them, the most confident / proud / relaxed / reliable / effortless.

After the next page, we provide an overview of the 15 video prototypes and explain how they are visualised. The visuals will be repeated in the results section. There we explain how we designed the movement of the "perfect intensity" videos in more detail. We structured the explanation in this way to make it easier to interpret the results. Based on these explanations, it is also possible to deduce how we created the "extreme" intensity videos; therefore, they are not explained individually.

2D streetwise movement study

*Required

Movement #15

#15 - How "confident" is the movement? *

Uncertain	Confident	Overconfident
a feeling of uncertainty or lack of conviction; unconvinced of what one believes or says.	*a feeling of self-assurance arising from an appreciation of one's own abilities or qualities.*	*a confidence that is not justified; having too much confidence in one's own abilities or judgment.*
• risk-averse • self-conscious • indecisive • confused • insecure • shy	• risk-tolerant • self-aware • courageous • determined • optimistic • bold	• presuming • overbearing • overoptimistic • impulsive • foolhardy • ignorant

too little confidence — perfect amount of confidence — too much confidence

1 2 3 4 5

#15 - How "proud" is the movement? *

Self-deprecating	Modest	Arrogant
to make yourself, your abilities, or your achievements seem less important; to undervalue oneself	*behaving so as to avoid indecency, especially to avoid attracting attention*	*showing excessive self-satisfaction in one's abilities; presenting yourself as being more important than you are*
• overly humble • submissive • undervalued • embarrassed • insignificant • unnoticeable	• sober • discreet • unobtrusive • authentic • sincere • unsaturated	• smug • swagger • presumptuous • condescending • attention seeking • flamboyant

too little pride — perfect amount of pride — too much pride

1 2 3 4 5

#15 - How "relaxed" is the movement? *

Anxious	Relaxed	Unconcerned
feeling or showing worry, nervousness, or unease about something with an uncertain outcome.	*the state or quality of being free from agitation or strong emotion, not easily worried or excited.*	*showing a lack of worry or interest, especially when this is surprising or callous.*
• worried • concerned • uneasy • distressed • on edge	• calm • carefree • unconcerned • cool-headed • nonchalant	• apathetic • indifferent • uninterested • detached • bored

too little calmness — perfect amount of calmness — too much calmness

1 2 3 4 5

#15 - How "reliable" is the movement? *

Unstable	Reliable	Inflexible
likely to give way. likely to change or fail; not firmly established.	*not likely to give way or overturn; firmly fixed. sane and sensible; not easily upset or disturbed.*	*unwilling to change or compromise. not able to be changed or adapted to particular circumstances.*
• shaky • unreliable • inconsistent • reckless • unpredictable	• sturdy • trustworthy • coherent • well founded • reasonable	• rigid • stubborn • unadaptable • single-minded • uncompromising

too little stability — perfect amount of stability — too much stability

1 2 3 4 5

#15 - How "effortless" is the movement? *

Awkward	Effortless	Uncanny
causing difficulty or feelings of embarrassment and inconvenience; being hard to do or deal with	*(appearing to) require no physical or mental exertion. To achieve something with admirable ease.*	*strange or mysterious, especially in an unsettling way.*
• struggling • cumbersome • uncoordinated • inappropriate • clumsy	• with ease • flowing • smooth • graceful • natural	• odd • eerie • creepy • unnatural • abnormal

too little smoothness — perfect amount of smoothness — too much smoothness

1 2 3 4 5

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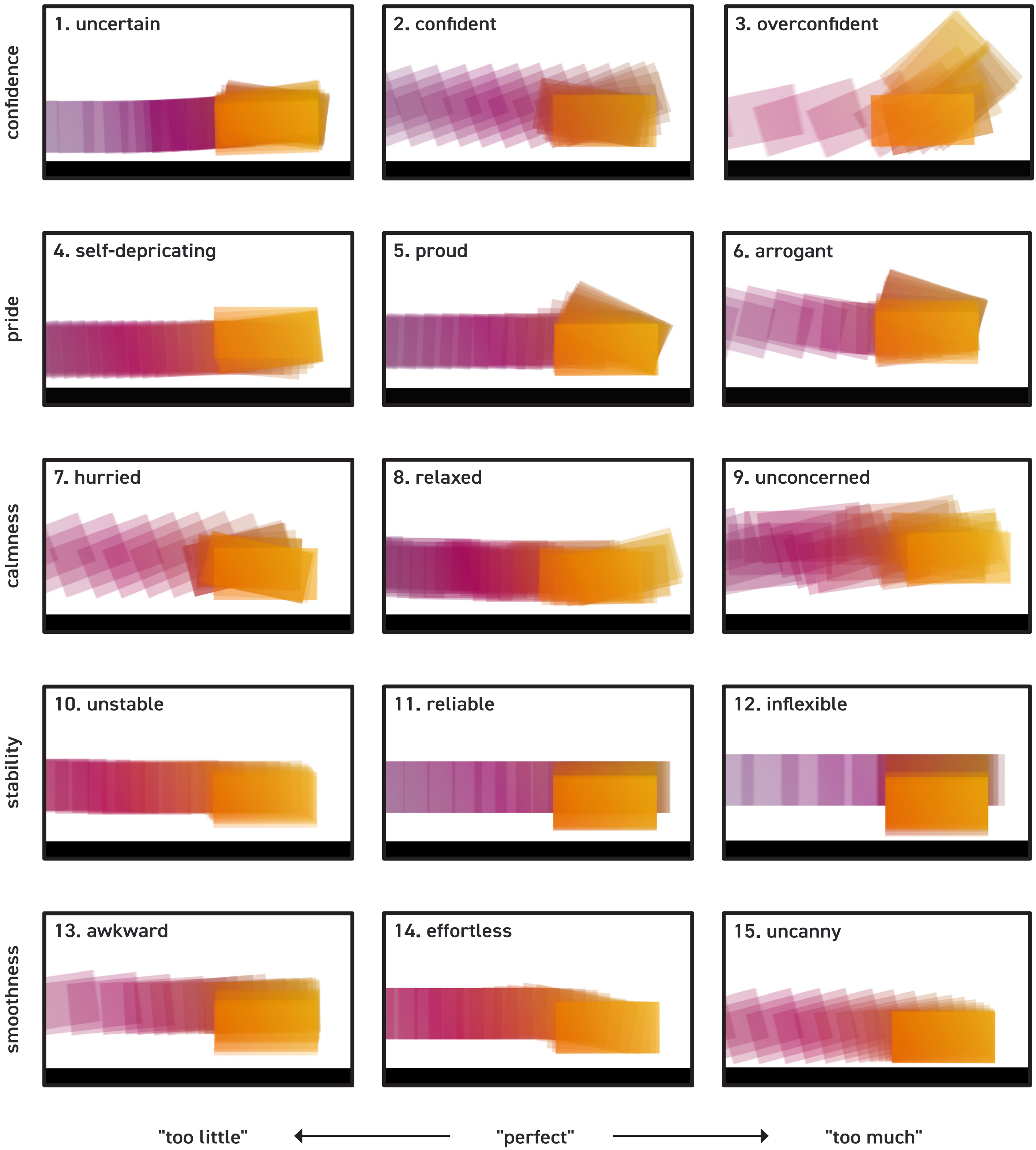
video prototype overlays - overview

To convey the movement of the video prototypes in this report, we exported the videos as image stills captured at 7.5 frames per second. Since the duration of the videos was deliberately kept between 3 and 5 seconds, this resulted, on average, in about 32 image stills per video overlay. We found this was just the right amount to capture nuanced details without the images becoming too cluttered.

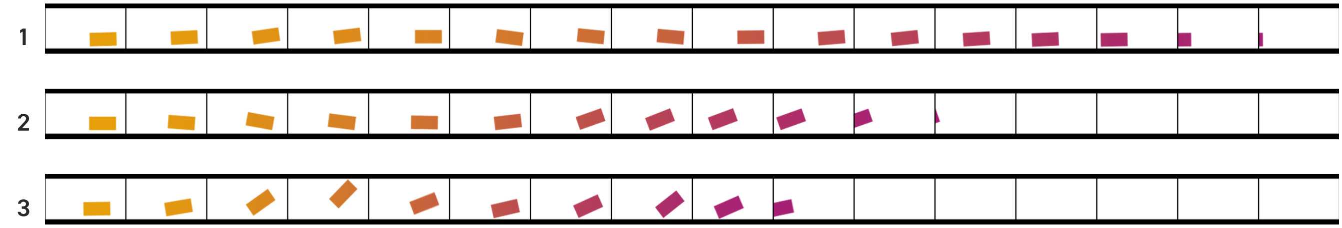
To better visualise the changes in movement, all stills were given a slight transparency. Additionally, we increased the image "brightness" over time so that stills towards the end of the movement become progressively lighter. Lastly, to make the movement changes even more apparent, we added a contrasting gradient overlay that transitions from orange to magenta.


confidence
1. uncertain
2. confident
3. overconfident
pride
4. self-depricating
5. proud
6. arrogant
calmness
7. hurried
8. relaxed
9. unconcerned
stability
10. unstable
11. reliable
12. inflexible
smoothness
13. awkward
14. effortless
15. uncanny
"too little"
"perfect"
"too much"

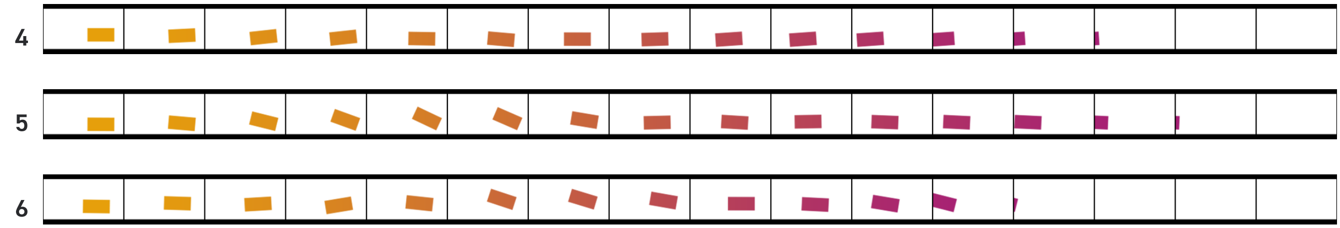
video prototype filmstrips - overview

Additionally, we produced the *filmstrips* on the next page to visually convey and compare the different video prototype durations. These images should be interpreted as strips of analogue film. As indicated by the colour gradient, they should be read from left to right. Each filmstrip is made up of 16 images stills, as more than that made them too small and narrow to fit on a single page.

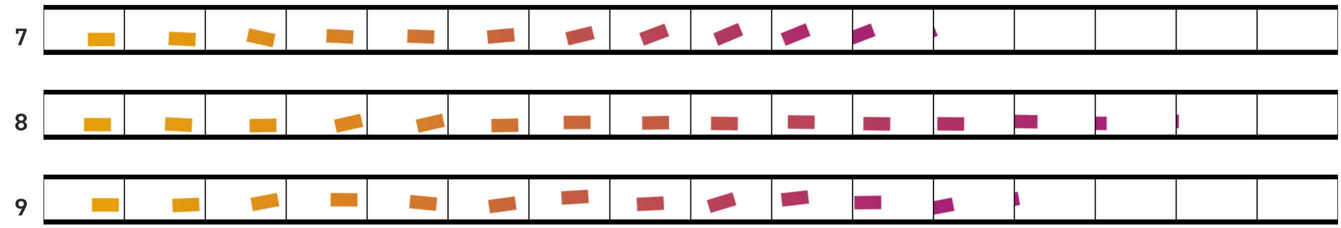
confidence spectrum



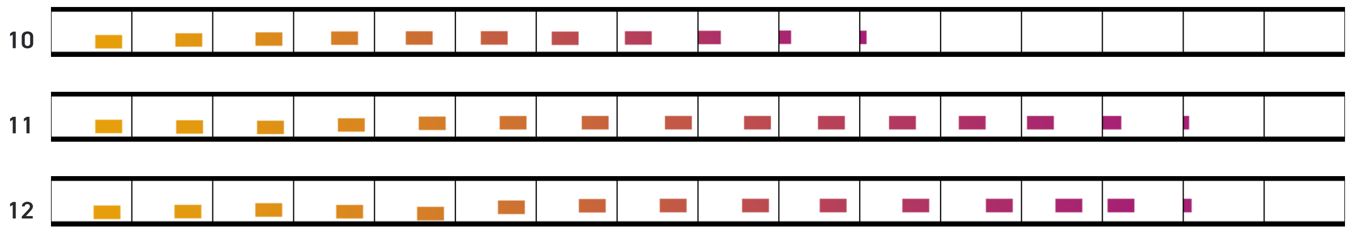
pride spectrum



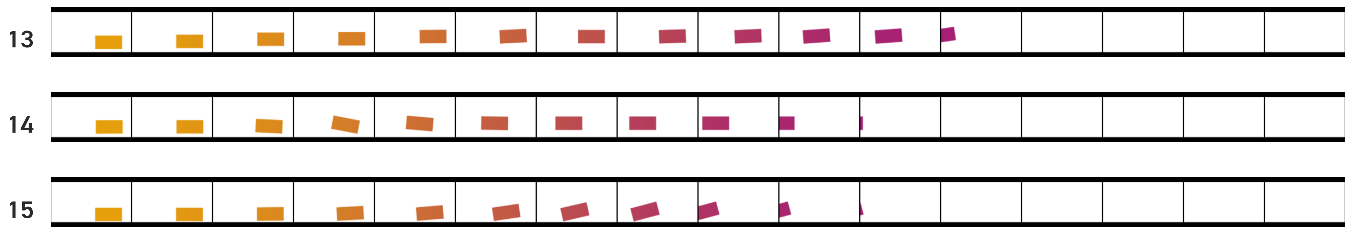
calmness spectrum



stability spectrum



smoothness spectrum



confident movement explanation

The confident video prototype aims to be deliberate with a healthy amount of smoothness. The movement was made with a strong emphasis on sharp in and sharp out. The most influential principles are Kinesthetic Response, Consistency and Spatial Relationship.

We found that Squash & Stretch, Arcs, and Secondary Action had a negative effect; if your goal is to create a confident movement, these principles should be avoided.

results

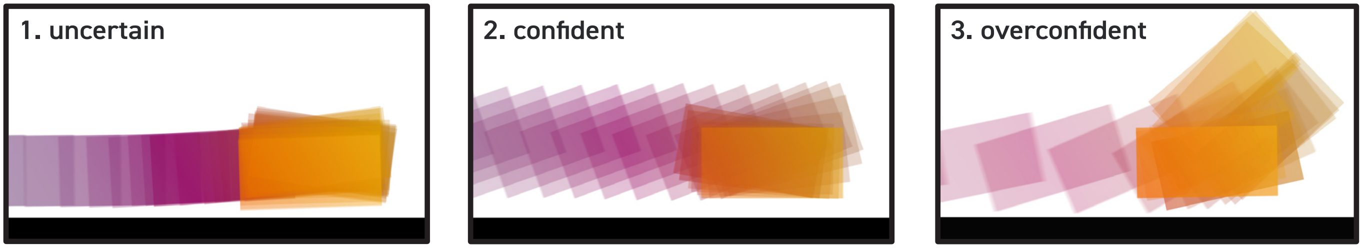
Overall, the results from the confidence spectrum videos are incredibly distinct.

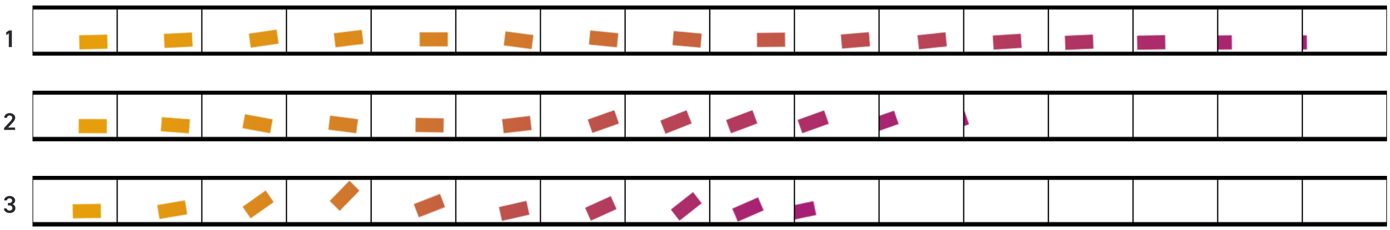
Video no.1 almost exclusively received very low scores. The majority of the qualities received a score of 1, with the remainder mainly receiving a score of 2. As we had hoped, the confidence quality received the most low scores.

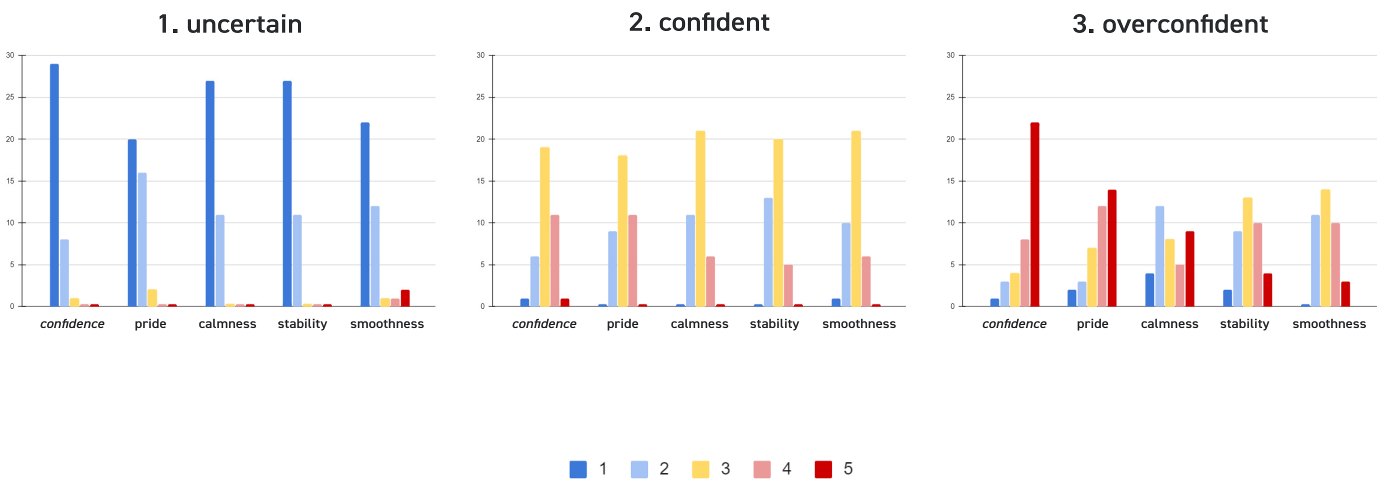
Video no.2 received many scores around the centre of the Likert scale. None of the qualities really stand out.

Video no.3 received a lot of high scores, with the confidence quality receiving the most. The quality with the 2nd most high scores is pride.

confidence spectrum







proud movement explanation

The proud video prototype aims to be *present* without being *obtrusive*. We found this unobtrusive presence can be achieved when movements *ease in* but *end sharp*. Movements are allowed to take their necessary time but should not be too exaggerated. The essential principles are Duration and Staging & Clarity.

We found that Repetition, Overlapping Action and Consistency had a negative effect; if your goal is to create a proud movement, these principles should be avoided.

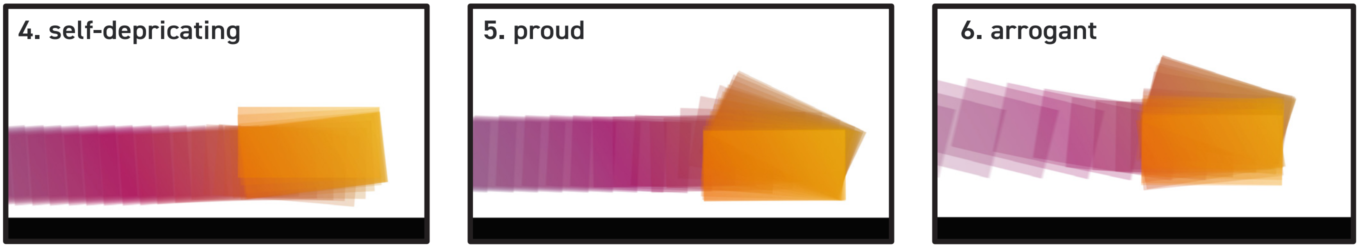
results

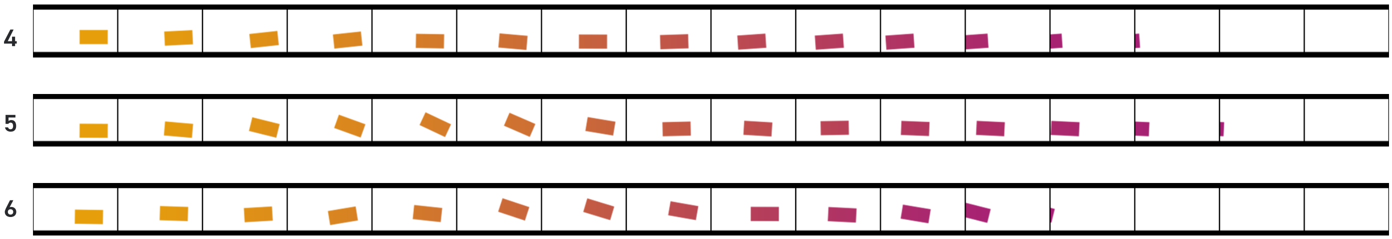
Out of the pride spectrum videos, video no. 4 received the lowest scores overall. However, the qualities of confidence and smoothness received more low scores than the other qualities. According to many participants, the video was still sufficiently proud.

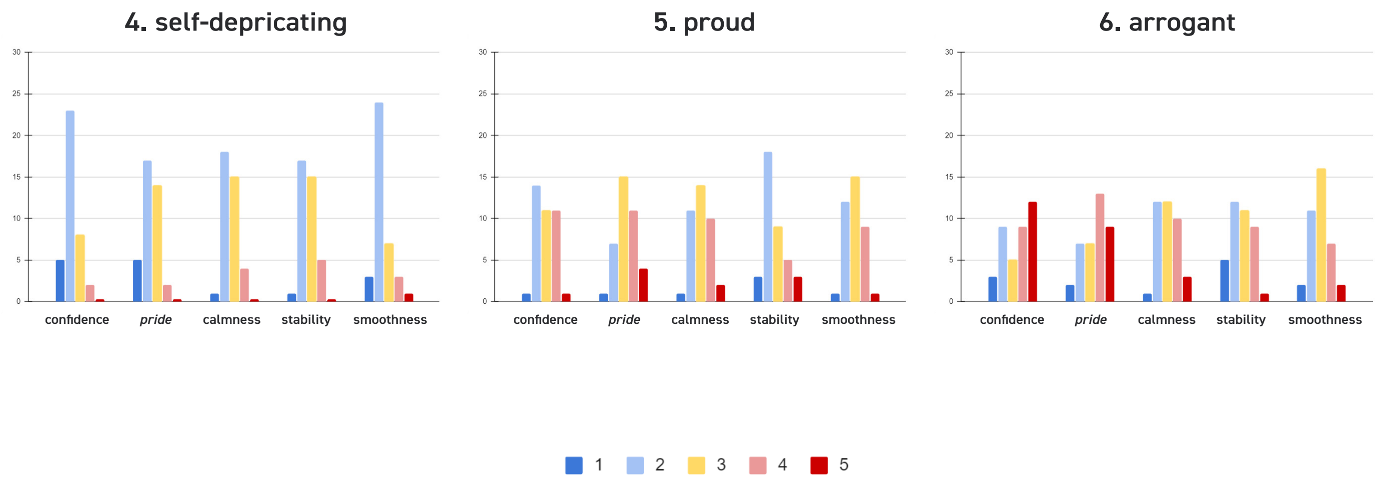
Video no.5 received many scores around the centre, albeit with quite some deviation. Surprisingly, the quality of stability stands out because it received the most low scores.

Video no.6 also received quite a few scores around the centre. However, this time the qualities of confidence and pride clearly received the most low scores.

pride spectrum







relaxed movement explanation

The relaxed video prototype aims to achieve low-damping movement and therefore avoids any sudden changes in direction. If a sudden change in direction is required, Squash & Stretch can be used to smooth out the movement. Finally, we use Timing & Rhythm together with Arcs to create a slight "bobbing" motion. This gives the robot a flowing attitude.

The relaxed quality is remarkable in the sense that we did not find a movement principle that had a negative effect. However, Repetition, Kinesthetic Response, and Consistency seemed to have very little influence.

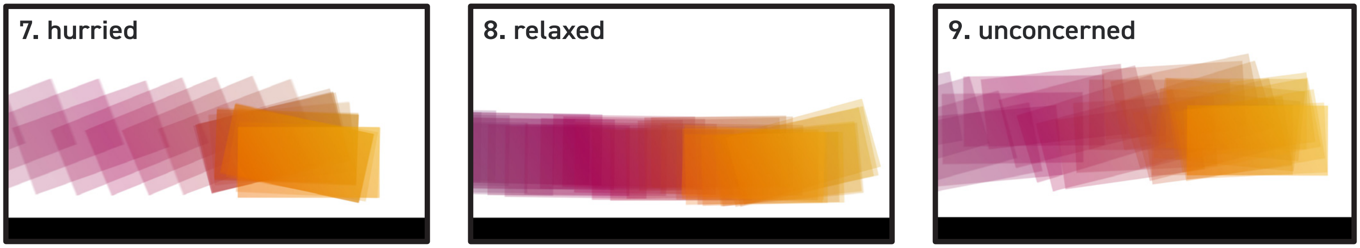
results

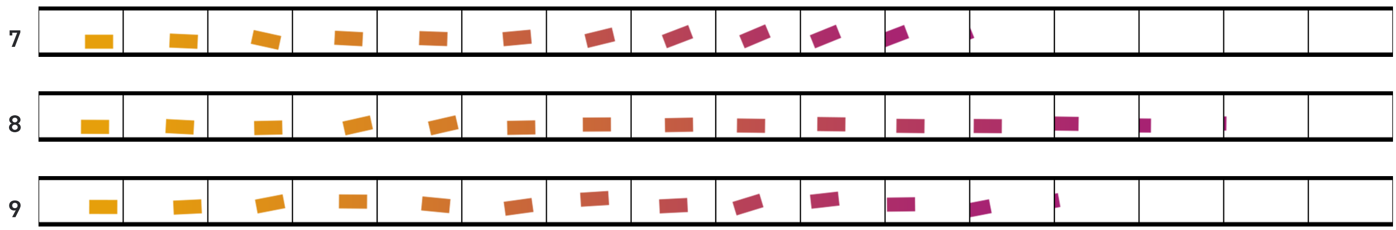
Of the calmness spectrum videos, video no. 7 received the lowest scores, with the quality of calmness receiving the most scores of 1.

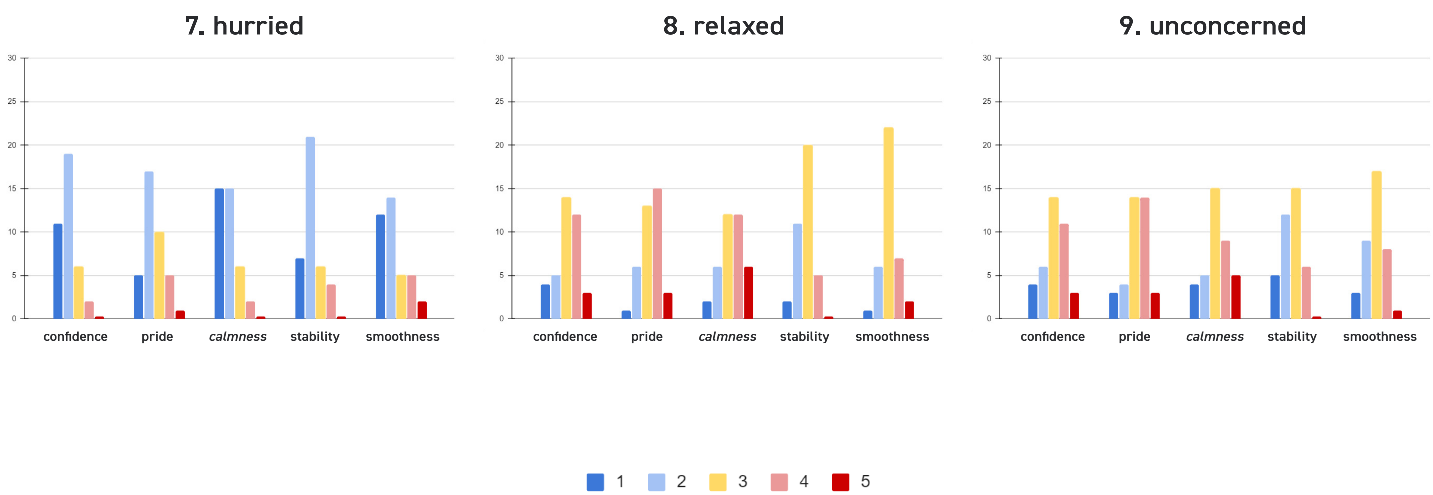
Video no. 8 received many scores around the centre but also quite a few high scores. Especially for the qualities of confidence, pride, and calmness. Surprisingly, calmness even received the most scores of 5 out of all qualities! Many participants did find that the movement had perfect stability and smoothness.

Video no. 9 received similar results as video no. 8, despite the movement being a lot more energetic. The video did, however, receive lower scores for stability and smoothness.

calmness spectrum







reliable movement explanation

The reliable video prototype aims to be predictable and straightforward. The principles that contribute the most are Anticipation, Consistency and Readability & Focus. The principles Squash & Stretch, Arcs, Overlapping Action, and Secondary Action were avoided as they had a negative contribution.

We found that Squash & Stretch, Arcs, Overlapping Action, and Secondary Action had a negative effect; if your goal is to create a reliable movement, these principles should be avoided.

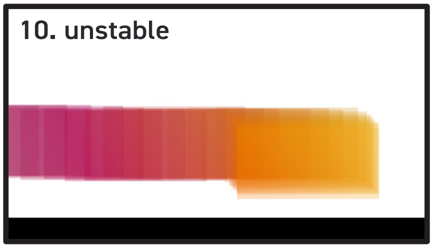
results

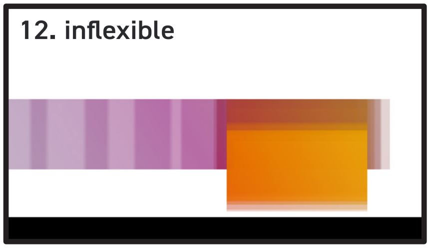
Of the stability spectrum videos, video no. 10 received the lowest scores overall. Out of the qualities, calmness and stability received the most scores of 1. The quality of pride is an exception as it received many scores around the centre.

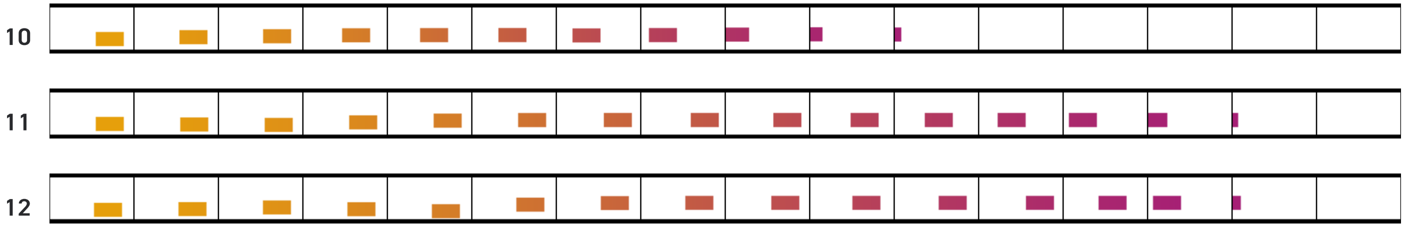
Video no. 11 distinctly received many perfect scores of 3, with only a few participants gravitating towards the higher scores.

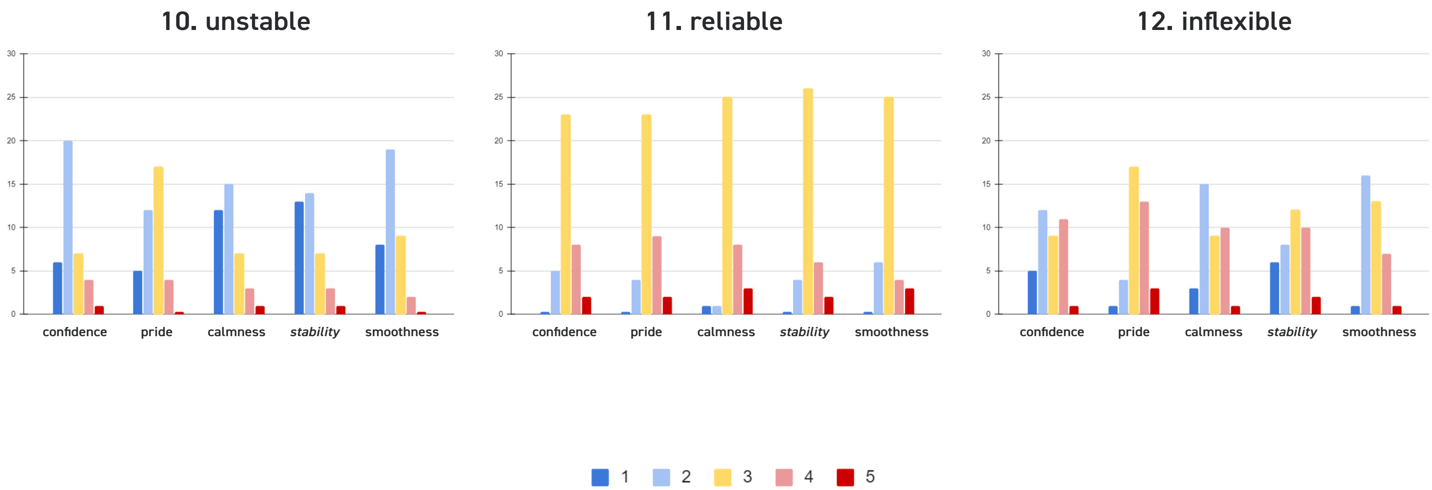
Video no. 12 received a lot of mixed scores. While nearly all the qualities received more high scores than video no. 10 and no. 12, not a single quality really stands out.

stability spectrum









effortless movement explanation

The effortless video prototype aims to convey that it can capably handle emerging challenges. To achieve this, the movement should appear easy. The single most important principle to achieve this is Overlapping Action. Being able to move in multiple directions simultaneously makes movement seem smooth, natural and intelligent.

We found that Tempo, Duration, Staging & Clarity, and Spatial Relationship had a negative effect; if your goal is to create an effortless movement, these principles should be avoided.

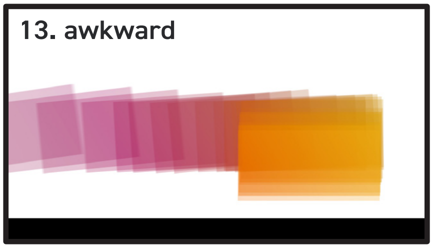
results

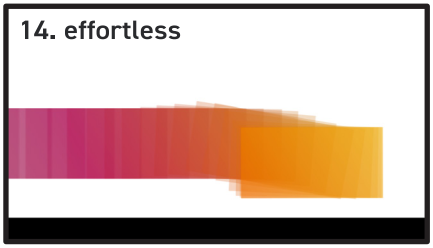
Of the smoothness spectrum videos, video no. 13 received the lowest scores. Additionally, the quality of smoothness received the most scores of 1.

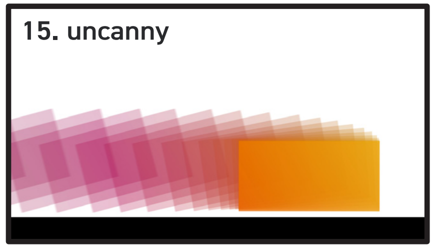
Video no. 14 has the highest amount of perfect scores out of all videos! Coincidentally, the scores also have the lowest deviation.

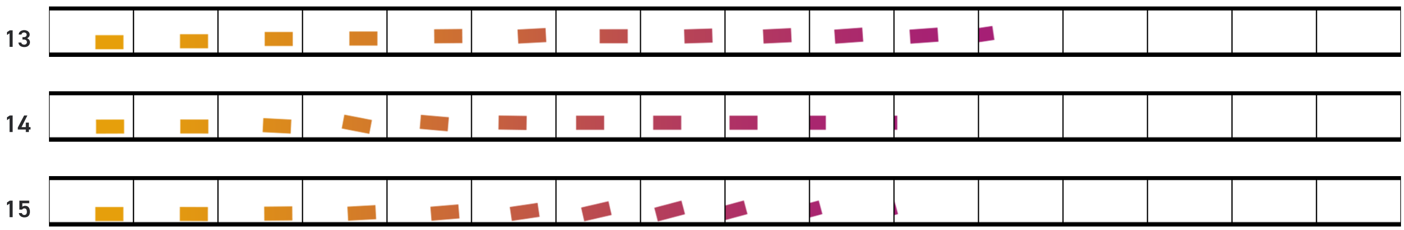
Lastly, video no. 15 also received quite a few perfect scores. Nevertheless, the video did receive the most high scores compared to the other smoothness spectrum videos.

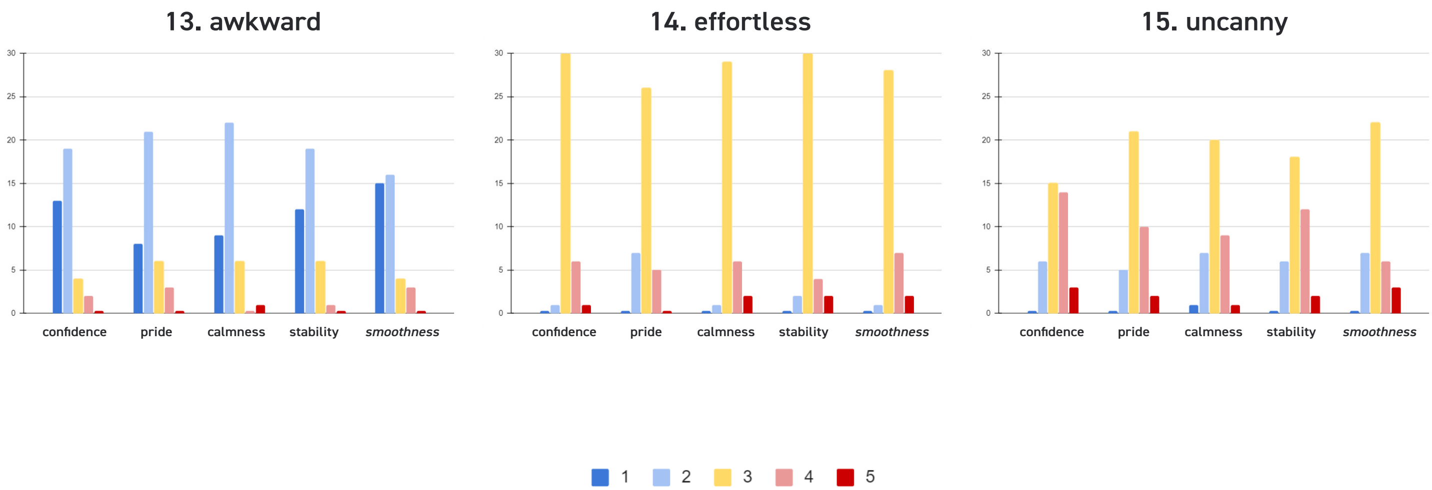
smoothness spectrum











The bar charts on the left show the average scores per video, but only from the intended streetwise qualities. For example, the scores for videos 1, 2, and 3 are for the quality of confidence, and the scores for videos 4, 5, and 6 are for the quality of pride, etc. Additionally, the corresponding standard deviations are displayed above the bar charts.

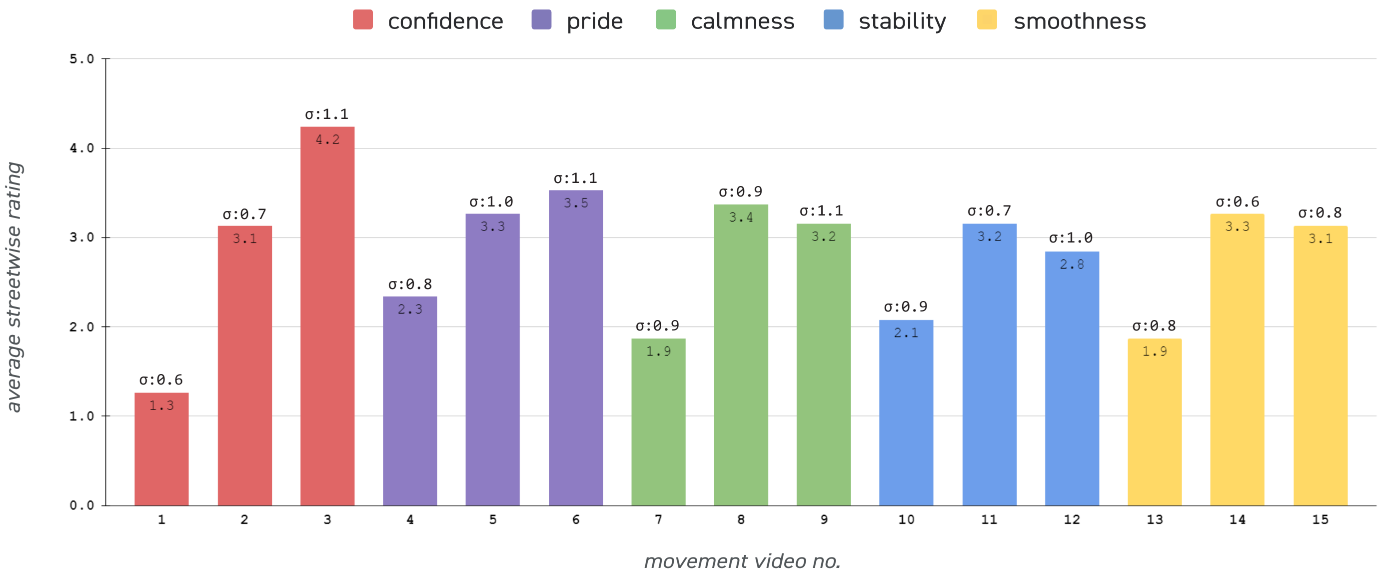
Finally, the answers to the final question of the form are displayed in a *confusion matrix*. The first row indicates the question that was asked (e.g. which movement was the most confident?), and the first column indicates the intended qualities of the videos that participants could choose. The numbers in the table indicate how often the answers were given. If our movements videos were unequivocally understood ,we would expect to see a diagonal dark blue line going from the top left to the bottom right. This would indicate that participants always chose the quality that we intended.

As was expected, there is quite some overlap between the different streetwise qualities. The first quality that stands out is *effortless*, which was correctly identified 21 times, making it the easiest quality to identify. Secondly, the *reliable* video prototype was also correctly identified by most participants, a total of 16 times. However, it was often confused with being the most effortless.

Thirdly, the *confident* video prototype was correctly identified 10 times, but slightly more people thought the video was the most effortless instead. The reliable video also scored high on confidence. Fourthly, the *reliable* video prototype was also most often identified as the most effortless, with only 9 people identifying it as the most relaxed.

Lastly, the *proud* video prototype was the most difficult to identify correctly. In fact, it was incorrectly identified the most often out of all qualities.

streetwise movement study - mean scores per video from intended qualities only



confusion matrix *questions*

answers

	confident	proud	relaxed	reliable	effortless	
confident	10	13	3	0	0	26
proud	2	4	2	0	3	11
relaxed	2	8	9	4	2	25
reliable	9	6	7	16	9	47
effortless	12	4	14	15	21	66
	accuracy: 0.3428					

discussion

Visualising the Likert scale scores with histograms provided rich insight into the collective decisions of the participants. The results indicate that our interpretation of the movement theories is on the right track; the videos from the confidence spectrum are the prime example of this as they received the most distinct scores. Additionally, their results clearly correspond with the intended intensities.

The results for the pride spectrum show a similar but less pronounced progression for low to high. However, due to the higher standard deviation of these results, it is hard to tell the significance of these minor differences.

The remaining qualities: calmness, stability and smoothness, all showed a similar pattern in their answers. While the low-intensity videos clearly received the lowest scores overall, the perfect and high-intensity videos received very similar mean average scores. The only difference in the scores of these videos was in their standard deviation, which was lower for the perfect intensity video in the case of stability and smoothness.

The results cannot tell us why the ratings are the way they are. Since the participants already had to answer over 75 multiple choice questions, it was unfeasible to ask them to substantiate their answers. Besides, most participants would have known very little about movement theories, making it hard to explain why they feel a certain way.

conclusion

The 2D movement study evaluated the efficacy of our interpretation of the movement theories in creating movement prototypes that express our behavioural streetwise qualities. **We can conclude that the method we used is moderately effective. Overall, there are measurable and distinct differences between the resulting video prototypes. However, movements should be reevaluated when the intended quality did not receive the highest score or when they received a high standard deviation.**

For a follow-up study, it would be advisable to iterate upon the unclear movements. By focusing on only one of the qualities at a time, it would be more feasible to inquire participants about their reasoning. When the goal is to fine-tune the interpretation of the movement theories choosing participants with a background in animation could also significantly improve the reliability of the results.

chapter 5

DELIVER

introduction

This chapter contains our third and final evaluation, which will be the basis for our recommendations in chapter 6. The purpose of the evaluation is to establish if our proposed degrees of freedom are a justifiable investment. In order to make this claim, we want to determine how our streetwise movement concept compares to a traditional delivery robot without additional degrees of freedom.

As mentioned at the start of chapter 4, we aim to achieve this by evaluating our findings with a *3D video prototype scenario*. In this scenario, we present 2 versions of the same delivery journey, one with a "streetwise" delivery robot that can manipulate its pitch, roll and height and another with a "non-streetwise" delivery robot that lacks these degrees of freedom.

We briefly discuss the animation process that allowed us to produce the 3D video prototype scenario, and we describe the method used to evaluate the scenario. Finally, we provide an overview of the results and present the conclusions.

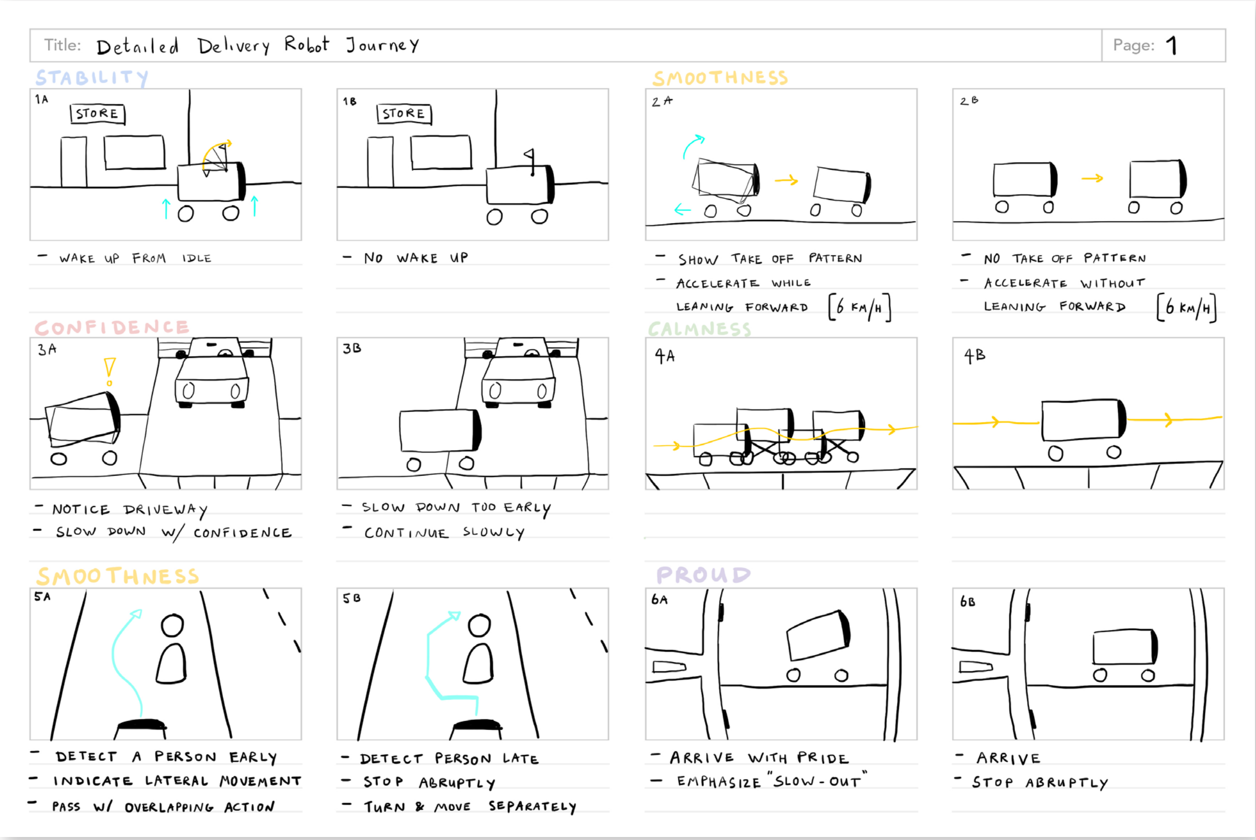
3D animation process

We wanted to create a semi-realistic environment for the final evaluation that allows the viewer to put the delivery robot and its actions into a relatable context. In preparation for the animation, we made the storyboard shown on the next page. The storyboard contains two different versions of the same delivery scenario. Version A describes the journey of a "streetwise" delivery robot that can control its pitch, roll and height, and version B describes the journey of a traditional delivery robot without any additional degrees of freedom.

In the delivery journey of version A, every scene includes an action based around one of the streetwise qualities. No method has been developed to decide when to employ which qualities; therefore, we used our intuition to decide which qualities felt the most appropriate.

Additionally, the delivery journey is designed around two *critical gestures*. The first critical gesture is noticing and passing a driveway, which is considered a high-risk area. The second critical gesture is passing two preoccupied pedestrians on a narrow sidewalk.

3D scenario - storyboard

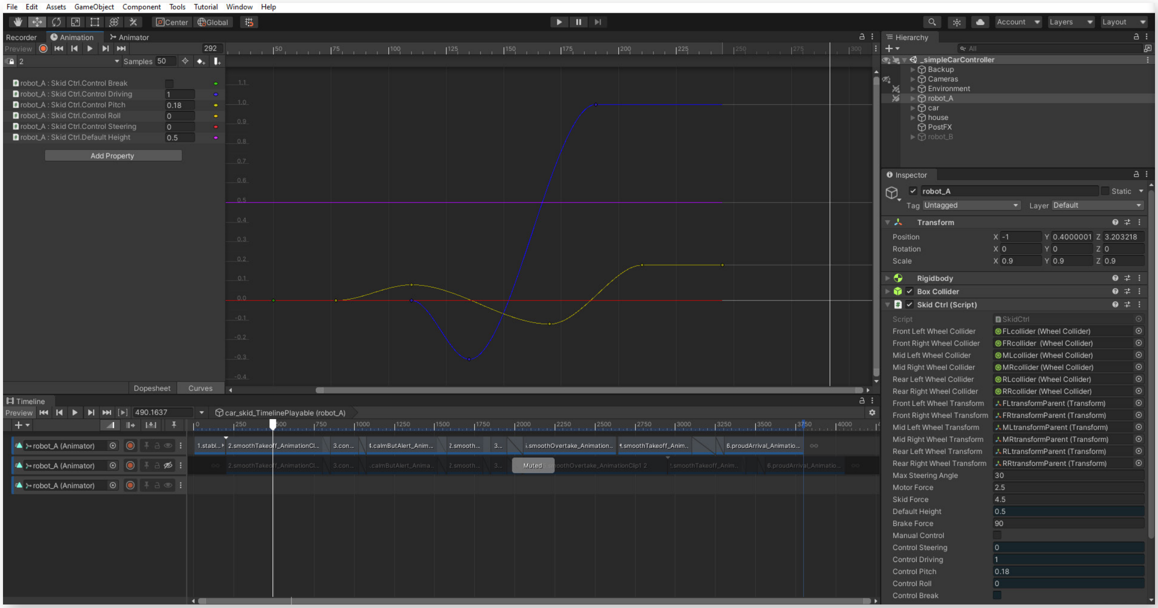


The 3D animations for our video prototype scenario were made using Unity. Due to its convincing real-time rendering, elaborate scripting possibilities and active online community, Unity turned out to be a tremendous digital prototyping tool. Environmental assets were made using a combination of Blender and Unity's built-in 3D modelling tool: ProBuilder. The only exceptions are the low-poly trees and clouds, which were downloaded from the Unity asset store. The 3D delivery robot mock-up was made using a combination of Blender and SolidWorks.

To make it seem like the delivery robot has a suspension that is affected by gravity and inertia, we used Unity's wheel collider system. This system provides the delivery robot with ground collision detection, wheel physics and a slip-based tire friction model. With the proper settings, it really appears as if the digital model has some weight to it. Besides making the simulation more realistic, the wheel colliders prevent us from tediously having to key-frame the effect of different movements on the robot's suspension system.

To animate the delivery robot with the wheel colliders, it is no longer possible to key-frame the 3D model's transform property. Instead, we had to write a small script that adds an input variable for each desired degree of freedom. These variables were then animated by adjusting their value between -1 and 1. An example of the resulting animation curve can be seen on the next page, together with an image still of the associated scene.

3D scenario - Unity Timeline & Animation Curves



3D scenario - scene 2A - smooth take-off

final evaluation method

We will conduct a series of qualitative interviews as our final evaluation method to determine if version A (the streetwise robot that moves with extra degrees of freedom) is perceived to be more streetwise.

Before the interview, we only told the participant that we would show them 2 videos demonstrating the same delivery journey but with different versions of the same delivery robot. What video the participant got to see first was chosen at random to prevent order bias from influencing their responses. The questions were asked directly after watching the first video to make the events easier to recall.

We started with broad and open questions and moved to more specific and closed questions towards the end. By asking the questions in this order, we encourage the participants to first think for themselves and minimise the chances of influencing their answers.

During the interview, the following questions will be asked:
Q1. Could you describe what you saw? What happened?
Q2. What three words would you use to describe the robot as you saw it?
Q3. I have a list of words here [show the 18 items from the The Robotic Social Attributes Scale in a random order], which of these are most applicable?

The purpose of question 1 is to find out which actions participants tend to notice and how they interpret those actions. We present the answers based on whether the participants gave an *emotive* or *neutral* description. We expect participants to use emotive words to describing version A and neutral words to describe version B.

The purpose of question 2 is to find out which qualities stand out the most when participants are asked to describe the different versions of the robot. When describing version A, we hope to see that participants unknowingly come up with the synonyms we used to describe our streetwise qualities at their "perfect" intensity. We expect version B to receive more negative descriptions associated with the extremes intensities of our streetwise qualities.

Finally, the purpose of question 3 is to find out which words participants would choose if they have to pick them from the RoSAS scale, a predetermined list of 18 items specifically designed to evaluate social robots. The items are divided into the categories competence, warmth and discomfort. We expect version A will be more closely associated with *warmth* and version B with *discomfort*.

results

A total of 14 participants completed the interview. Overall, participants did a great job at providing detailed answers without asking them to elaborate. The answers are diverse and contain many rich insights. The following 6 pages provide a side-by-side overview of the results relevant to versions A and B.

question 1 - version A (streetwise)

Emotive descriptions (9)	Neutral descriptions (4)
I saw an adorable driving little vehicle/robot that has to wake-up and take a run-up to start moving and when it does, it becomes very determined and focused when it's driving without being disturbed. When it met the car or the pedestrian, it was almost like it got startled a little or at least it got taken out of its hyperfocus and it seemed to think about what it was going to do now. When the robot met te car and crossed it, it seemed like a happy child skipping across the road, but when it met the pedestrians, it swirled around them like it was a little annoyed that they weren't going out of its way. A slow moving delivery robot driving relaxed through the neighbourhood to deliver a package. The rolling movements seem a bit random and not adding much external signalling. It slowing down before crossing the road where the car was waiting it showed great awareness. it made a smooth movement to go around the people talking on the sidewalk. In some ways, you could say that , the car looks lonely . The pointing down parts make it look anxious 😟 maybe . He avoids the 2 people , but doesn't rush past , as though , hoping they would notice it . Maybe even talk to it . It rushes when alone , to get back he , but stops when near another car or person . Wry interesting 😕 . The car accelerated when the path was clear and slowed down in scenario's where uncertainty was higher due to possible interaction with other people/objects. It seemed hesitant during these scenarios due to much braking and slow accceleration. It also showed some hesitation when it was near its destination. The driving style seemed relatively aggressive, either accelerating or braking most of the time. Acceleration and deceleration motion seems 'backwards' (front 'should' go up when accelerating and vice versa?) Robot starts the delivery journey from the store. It moves different, I think too much unnecessary expressions. From its expression I understand that it aims to be fast. Then it sees the car and tries to slow down. The way the robot move I would say is awkward. Then there are two pedestrians, the robot moves around them. It tries to avoid them but from the movement I also have the feeling that it wants to be kind of social with them. At the end it arrives at the final delivery destination. The customer is happy. The robot was drive the same route as in the previous video, but he had a completely different appearance; he came across as way more playful and human, like he was capable of feeling emotions. He didn't move in a constant way like in the previous video and he stopped occasionally to take in his surroundings. When he encountered the two people he didn't interact with them, but drove around them in a funny and exaggerated way. A small car/robot drives down the street, dodging people and traffic. It looks like he's going for his target very decisively. Because he keeps accelerating when there is an empty space on the road and the way he leans forward. this one looks cute! It feels more like a character from Cars. That feels like a positive thing, its not just an object driving around, its definitely not a human but it feels like it has feelings. Whereas the first one is very strict and functional. Its nice how the robot anticipates on what it sees. You get an idea of what the robot will be doing, and how it will act. It feels more natural but also a little bit more careless as its bumping around and being happy. Funky little robot that smoothly runs along a street to deliver a parcel from store to customer. Its suspension must be broken tho, since it operates the exact opposite to what a car would do when accelerating and braking :P It does give it some "character" when driving at "speed".	A driving robot is driving next to a road, and slows down when it detects objects like traffic situations (de oprit) or people, and based on the situation continues its journey by driving around it or by just going straight Automated delivery robot travelling along a footpath, slowing when approaching possible hazards (car pulling out of driveway, pedestrians standing in path) using exaggerated forward / backwards motions to indicate acceleration and deceleration. The car left the store to deliver the package to the house. On his way it encounters multiple obstacles, but he knows how to respond to the situation in a good way. It doesn't disturb the people on the sidewalk and also it recognizes the car. In the end it keeps waiting in front of the house. the video was very similar to 1B, but this time the robot moved its "body" along with the motions. it also stopped for the car. it seems rather small and beatable. I can imagine some people will want to hit this robot with their car. People with high cars also might not see this when they are driving and drive into it.

question 1 - version B (non-streetwise)

Emotive descriptions (5)	Neutral descriptions (8)
Automated delivery robot travelling along footpath. Although it appeared aware of hazards, it didn't show any obvious signals as to what it was intending to do... Avoiding the pedestrians seemed overly cautious and as a result, very unconfident. It looked like it was just going along at an even pace. Not rushing, just calmly heading to its destination. As it came up to the 2 people, it behaved a little bit oddly . Went very close to them as it slowed , almost to the point of stopping. It then followed a path right into the edge of the path. Reminded me a bit, of OCD. Acceleration seems smooth, almost unnatural with the frame moving only a small amount. Robot takes special care when moving around the people in its way, but is also careful when moving in front of the car. It seems confident when driving to its destination where it comes to a smooth stop. the first part i would describe as careless but very confident, whether the car is in the street or not he would just continue. It almost felt like he would run into the people because he was going very straight forward. When the robot deviates from its route it feels like its having a hard time and need to a lot of calculations. At the end the robot stops smoothly and in a correct manner. A small autonomous delivery robot drives from a store to a customer, presumably carrier a parcel. Along the way (smooth, paved streets) it detects and avoids objects calmly and calculated. Perhaps a bit too slow. It does have a neutral and non-threatening appearance, but seems easy to topple.	The robot is again driving, but this time doesn't indicate when it is accelerating or slowing down. It again is checking for people and traffic situations just like the last one. This is more like the traditional self driving robot I've seen (e.g. Amazons robots) I saw a small vehicle/robot go from a to b, but not that much else was happening. It stopped sometimes to determine how to adapt to the upcoming traffic and then it slowly continued its way. It really felt like a machine, so no character besides being serious and a bit boring. It felt like it was just following orders instead of going on an adventure. However, I feel like it made the robot seem a little more competent maybe, compared to when it would have more humanlike characteristics, as I would expect it to make humanlike errors. Then again, when it acts this way, I feel like people wouldn't care about it too much and treat it with less respect, and so it could get damaged a lot easier. The robot delivered the package from the store to the house. This time it all went a bit less fluently. It didnt stop for the car. It did avoid the people on the pathway however it was a bit on the late moment. The robot seems very slow moving. It was not doubting when crossing the street to wait for the car. But passing the people it doubted quite a bit and it seemed it had to find a way first before it could peform the movement. It seemed overly carefull there. it also seemed very emotionless since there was no other movement other then the driving. Robot starts its delivery journey from the store. First it passes in front of a car and trying to be careful. And second there are two people on the sidewalk. And the robot slows down. And the robot carefully navigates around these two pedestrians. Pedestrians don't seem to be aware of the robot. The robot was moving over the sidewalk until he encountered an obstacle; two people talking were blocking its way. He drove around them, but seemed to stop for a second when he was right next to the two people in the conversation, as if he was eavesdropping. After that, he continued his way in the same speed. A small robot car moves carefully along the sidewalk and seems to be mindful of the traffic and people on the street it is going around. At the end he stops at a house and I assume that is the address where he has to deliver something. A little wagon is going its way along the pavement from a store to a house. It moved around some pedestrians. It did not stop for the car. Is it considered a pedestrian? from the title I have deduced that it is a delivery robot

Neutral emotives words are highlighted yellow

Positive streetwise synonyms are highlighted green

Negative streetwise synonyms are highlighted red

Other words off interest are highlighted grey

As expected, version A received the most emotive descriptions whereas version B received the most neutral descriptions.

The "word clouds" on the next page provide an overview of the words participants chose to describe the different robots. Bigger words were mentioned more often.

question 2 - version A (streetwise)

Just as we had hoped, participants used a lot of our perfect intensity streetwise synonyms to describe the delivery robot in version A. Words like *aware, determined, natural, fluently, relaxed,* and *worry-free* indicate that our chosen movements as a whole managed to convey a robot that is streetwise!

There is, however, room for improvement, as negative words were also mentioned. For example, it appears that a few people found the movements in version A too exaggerated. Fortunately, this is something that can easily be fine-tuned by dialling down the intensity of the movements.

question 2 - version B (non-streetwise)

As expected, participants used more extreme intensity streetwise synonyms to describe the robot in version B. The words *slow, calm, emotionless, and small* were mentioned most often.

The word slow is particularly interesting because the robots drove at precisely the same speed in both versions! This likely indicates that pitching forward affects the perception of how fast the robot appears to drive.

word cloud - version A (streetwise)

word cloud - version B (non-streetwise)

question 3 - version A (streetwise)

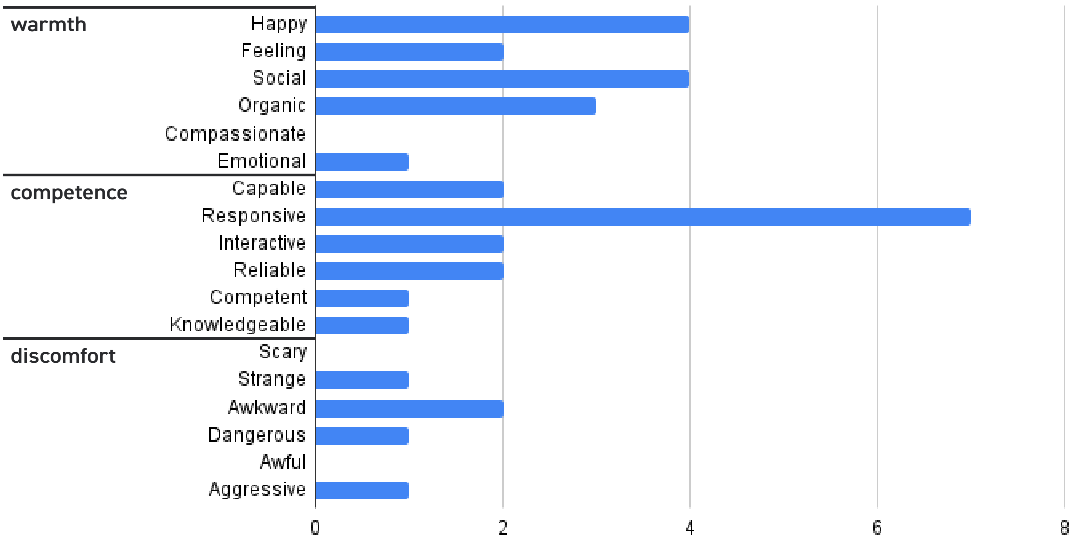
While reviewing the robot from version A, participants attributed 14 items from the warmth category, 15 items from the competence category, and 5 items from the discomfort category.

question 3 - version B (non-streetwise)

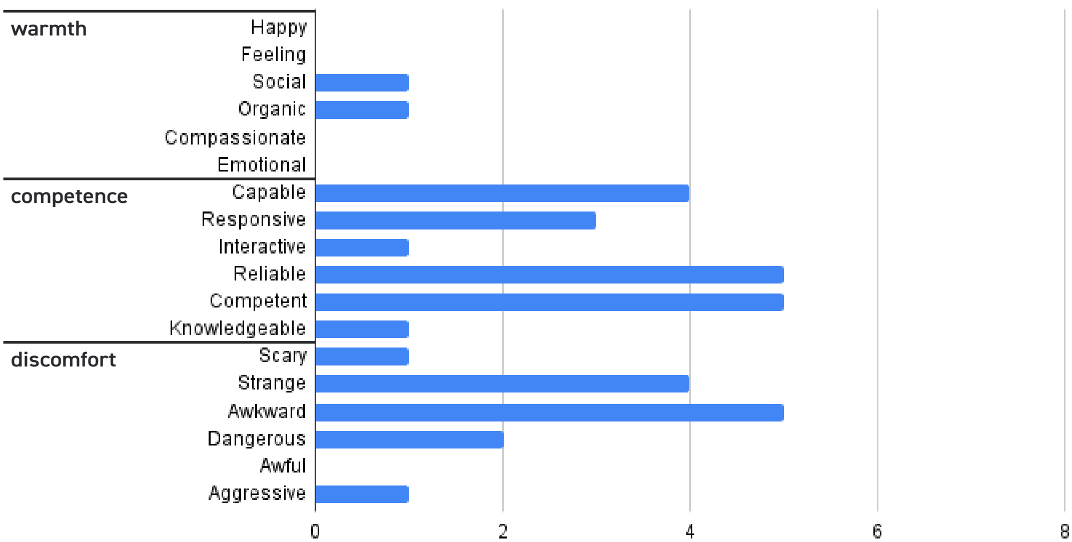
While reviewing the robot from version B, participants attributed 2 items from the warmth category, 19 items from the competence category, and 13 items from the discomfort category.

As expected, the delivery robot of version A received a lot more items from the warmth category than the robot from version B. Both versions received a comparable amount of items from the competence category, but where version B scores high on confidence overall, version A was mostly praised for being responsive, which makes sense since the additional degrees of freedom were used to actively respond to the environment. Finally, most participants described the robot without additional degrees of freedom as being *awkward* and *strange*.

results question 3 - version A



results question 3 - version B



chapter 6

RECOMMENDATIONS

aesthetics
While most participants described our 3D video prototypes in terms of actions and movement, a few participants describe them mainly in terms of aesthetics, using words like high-tech, modern, or even sterile. Aesthetics are important because they can significantly influence people expectations of a robot's abilities. For example, bystanders are more likely to become annoyed if a robot looks advanced but does not act like it. Therefore, future studies should explore the influence that carefully designed aesthetics can have on the interpretation of expressive movement.

dimensions
Besides aesthetics, we expect that the physical size of the prototype will also influence how the expressive movements are interpreted. For the sake of generalisability, our digital prototype was based on the dimensions of the robot from Starship Robotics since this is the most common delivery robot in the US and UK. Future studies should consider evaluating their prototypes in VR or by using a physical prototype.

active suspension
In our digital prototype, the degrees of freedom of our active suspension system worked like a black box. The wheel collider script we used only manipulated the delivery robots body to create the illusion of a suspension system. A future project should investigate how the proposed degrees of freedom can be physically implemented.

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