

THCI Coursework 2019

Essay 1: Improving The Efficacy Of Games for Change Using Personalization Models [2017]

Topic: Persuasive Technology - How might computer technologies be designed to encourage behavioural change for users' benefit and for the benefit of society at large? In recent years, this question has motivated a range of research under the title 'Persuasive Technology'. Especially current, in the light of government policy, is the potential for mobile and ambient technologies to 'nudge' behaviour change. In this coursework assignment you would review some of these developments, question what they have in common, and reflect on how a design science might be developed to tackle these questions. Important background is in the psychology of persuasion and influence.

Abstract: There has been a continuous increase in the design and application of computer games for purposes other than entertainment in recent years. Serious games—games that motivate behavior and retain attention in serious contexts—can change the attitudes, behaviors, and habits of players. These games for change have been shown to motivate behavior change, persuade people, and promote learning using various persuasive strategies. However, persuasive strategies that motivate one player may demotivate another. In this article, we show the importance of tailoring games for change in the context of a game designed to improve healthy eating habits. We tailored a custom-designed game by adapting only the persuasive strategies employed; the game mechanics themselves did not vary. Tailoring the game design to players' personality type improved the effectiveness of the games in promoting positive attitudes, intention to change behavior, and self-efficacy. Furthermore, we show that the benefits of tailoring the game intervention are not explained by the improved player experience, but directly by the choice of persuasive strategy employed. Designers and researchers of games for change can use our results to improve the efficacy of their game-based interventions.

INTRODUCTION:

Research:

- Determine whether personalization necessary in the context of serious games for health - developed models showing how people from seven gamer types [Nacke et al. 2013] respond to eight commonly-employed persuasive strategies [Orji et al. 2014].
- Then used model to design tailored and contra-tailored version of persuasive game for 2 common gamer types (Achievers and Conquerors) using 2 common persuasive strategies (Reward and Competition/Comparison).
- Results of large-scale randomized controlled study of 335 Achievers and Conquerors (272 valid participants) showed tailoring persuasive game increased effectiveness with respect to promoting desired changes in attitudes and intentions that lead to healthy behavior while contra-tailoring did not.

Findings:

- If we fail to consider gamer type, neither persuasive strategy emerges as more effective
- Considering gamer type reveals players only respond to tailored persuasive game intervention (Reward for Achievers and Comparison for Conquerors) and not to contra-tailored intervention, even though the underlying game mechanics the same.

- Parallel mediated regressions [Hayes 2013] show beneficial effects of tailoring not explained by improved player experience from personalized game that appeals more to that gamer type.
- Research relevant for researchers who investigate games as interventions in domains
- such as health.
- Guide design decisions of game designers and developers.

Main contributions:

1. **Importance of tailoring games for change:** controlled large-scale experiment. Tailoring serious game's design to a player's personality type improved game's effectiveness, as measured by change in attitude, self-efficacy, and intention.
2. **Games for change can be tailored by adapting only persuasive strategies and not game's mechanics, themes, or narrative:** Major drawback to tailoring persuasive games is cost –work involved in designing/adapting persuasive games.
3. **Benefits of tailoring game-based intervention not mediated by improved player experience:** explained directly by choice of persuasive strategy employed.
4. **Persuasive games designed using single appropriate strategy can be effective:** developers and designers do not have to employ multiple strategies to make games effective.

BACKGROUND:

- Design of serious games attracted attention of HCI researchers.
- Games effective for intended behaviour change [Fujiki et al. 2008; Orji et al. 2012].
- Use of serious games for health promotion received special attention due to importance.
- Digital games are known to motivate players for hours at a time and encourage play that culminates in completion of a game [Ryan et al. 2006]
- Continuous increase in the design and application of computer games for purposes other than entertainment
- Games can be strategically designed to:
 - overcome addictive behaviours [King and Tester 1999],
 - promote personal wellness [Grimes et al. 2010; Consolvo et al. 2009; Orji et al. 2013; DeSmet et al. 2014],
 - avoid risky sexual behaviour [Jemmott et al. 1992; Duncan et al. 2014]
 - manage chronic diseases [Brownson and Kumanyika 2007; Lieberman 2001].
- Serious games (*games for change*) applied as digital interventions in domains including
 - smoking cessation [Khaled et al. 2008],
 - energy conservation [Bang et al. 2006],
 - healthy eating [Orji et al. 2012; Orji 2014],
 - physical activity [Berkovsky et al. 2010]
- shown to
 - motivate behaviour and attitude change [Stokes 2005; Baranowski et al. 2008; Gerling et al. 2014],
 - persuade people [Bogost 2007; Fogg 2003],
 - promote learning [Kiili 2005]
- “one-size-fits-all” approach not effective because different types of people are motivated by different persuasive strategies [Orji et al. 2013],
- Strategy that worked well with one group of people may demotivate a different group [Orji et al. 2013; Kaptein et al. 2012].

- Increasing demand for persuasive games tailored to the target users' motivation [Khaled 2008; Berkovsky et al. 2010].
- Although games for change designed with group in mind (e.g., [Khaled et al. 2008]), researchers only started to model how groups of people respond to the differing strategies used in games for change [Orji et al. 2013; Orji et al. 2014]
- “serious games for health”: entertain, educate, and train players, while attempting to modify aspect of player’s health behavior [Stokes 2005].
- primary purpose: changing user’s behavior or attitude using various persuasive strategies [Fogg 2003; Orji et al. 2013; Khaled et al. 2009].
- (www.gamesforchange.org).
- Persuasive strategies:
 - Persuasion, i.e., attempt to influence or reinforce behaviors, attitudes, feelings, or thoughts [Khaled et al. 2009].
 - Achieved using various strategies. For example, [Fogg 2003] developed 7 persuasive tools, and [Oinas-kukkonen and Harjumaa 2008] built on Fogg’s strategies to develop 28 persuasive system design principles.
 - Study identified Competition, Simulation, Self-monitoring, Suggestion, Customization, Praise, Reward, Comparison, Cooperation, and Personalization, as 10 commonly-employed strategies in design of games for change [Orji et al. 2014]. Detail in Oinas-kukkonen and Harjumaa 2008
- Games for change:
 - Effective if they successfully educate users about certain topics [Busch et al. 2015].
 - Within health domain, several games for change developed employing one or more persuasive strategies [Orji et al. 2013; Shegog 2010].

Healthy eating

- National Mindless Eating Challenge (NMEC): mobile phone-based health game for promoting healthy eating [Kaipainen et al. 2012].
 - Players care for virtual pet or plant which requires them to follow healthy eating recommendations.
 - Employs Reward, Comparison, Customization, Suggestion, and Personalization strategies.
 - Personalisation: Player selects initial eating goal - based chosen goals, players assigned tasks relevant to goals.
 - Customisation: Enable / disable game features.
 - Suggestion: At end of each month, players given new suggestions.
 - Comparison and Reward: Players receive Rewards and compare performance with others.
- LunchTime: motivating healthy eating [Orji et al. 2012].
 - Reward, Competition, Comparison strategies.
 - Players = restaurant visitor
 - Goal: choose healthiest option.
 - Points = Reward. Compare performance

- RightWay Café: Customization, Competition, Simulation, Personalization, and Suggestion to promote healthy eating and physical activity [Peng 2009]. Players manage avatar's daily consumption and physical activity to reach optimal weight.
 - Customisation: Players create avatar using name, weight, height, age, gender, physical activity, and body frame
 - Suggestions: personalised
 - Competition: player who best managed daily diet wins.
 - Simulation - At end of week game simulates weight change.

Physical activity:

- Neat-o-Games [Fujiki et al. 2008] - *Competition, Comparison, Reward, and Self-monitoring* to promote physical activity.
 - Activity (monitored using accelerometers) used to control speed of avatar in racing game. Players awarded activity points. Compared and winners announced.
- Fish 'n' Step [Lin et al. 2006] - *Competition, Cooperation, Reward, and Self-monitoring and Feedback* in a game to promote physical activity.
 - Cooperation and Competition: Player's step count linked to growth and activity of virtual fish in a tank of other fish.
 - Compete as individual or team - feedback on progress.
 - At the end, players rewarded by changing appearance, number, and size of fish.
- Smoke? [Khaled et al. 2008] - *Reward, Simulation, Cooperation, and Praise*.
 - *Simulates* 6 weeks of virtual character whose life controlled - actions to quit smoking. Players learn how to overcome barriers.
 - Also convince friend quit smoking –*Cooperation*.
 - Reward: At end, players observe benefits of their decisions.

Disease management:

- Packy and Marlon [Brownson and Kumanyika 2007]- self-manage type 1 diabetes by monitoring blood sugar, providing insulin, and managing food.
 - *Cooperation*. Characters help each other.
 - *Customization*: Players set desired insulin dose
 - *Self-monitoring*: monitor fluctuation in blood glucose.
 - GlucoBoy [Slater 2005] –game for diabetes self-management.
 - Bronki the Bronchiasaurus [Lieberman 2001] adventure game aimed at imparting asthma management skills.
- Review not exhaustive, but good representation of practices.
 - Competition and Reward frequently employed [Bell et al. 2006; Grimes et al. 2010; Orji et al. 2012].

Tailoring:

- one-size-fits-all limited especially for motivating health behavior [Khaled et al. 2008, Berkovsky et al. 2010].
- Few designed with specific user group in mind.

- *Smoke?* [Khaled et al. 2008] investigated tailoring based on cultural background:
 - o 2 versions: collectivist and individualist using strategies appropriate for each.
 - o Result: individualist players persuaded more by individualist version than collectivist version.
- *PLAY, MATE!* [Berkovsky et al. 2010] personalized difficulty level by adjusting reward times for novice and experienced players. Balanced number of activities performed by novice and experienced players without affecting perceived enjoyment but same strategy – *Reward* – applied to every player.
- In initial examples, choice of persuasive strategy not a source of tailoring.
- Influence of gamer personalities and player models (e.g. [Nacke et al. 2013; Bartle 1996; Houlette 2003]) on efficacy largely ignored.
- Treating gamers as monolithic bad design [Bartle 1996; Bateman and Nacke 2010; Yee et al. 2012] – what works for individual may demotivate another [Orji et al. 2013].

RESEARCH QUESTIONS:

- RQ1: Does tailoring games for change to player type increase their persuasiveness?
- RQ2: Are the beneficial effects of tailoring mediated by an improved play experience?

DEVELOPING PERSONALISATION MODELS:

- Orji et al. 2014 with 1108 participants, gathered data on how 7 gamer types defined by BrainHex model [Nacke et al. 2013] – *Achiever, Conqueror, Daredevil, Mastermind, Seeker, Socializer, and Survivor* – respond to 10 persuasive strategies employed in games for change – *Customization, Simulation, Selfmonitoring, Suggestion, Personalization, Praise, Reward, Comparison, Competition, and Cooperation* [Orji et al. 2014].
- Participants responded to questions related to how likely 10 strategies (depicted through storyboards of character interacting with game promoting healthy eating [Orji et al. 2014]) would influence eating decisions.
 - o Feedback gathered using validated scale for measuring perceived persuasiveness [Drozd et al. 2012].
 - o Also asked participants to complete BrainHex questionnaire [Nacke et al. 2013] to determine gamer type.
- Validating storyboards depicted intended strategy [Orji et al. 2014] and data suitable to conduct factor analysis [Kaiser 1960], performed Exploratory Factor Analysis [Costello and Osborne 1994], which revealed participants responding to eight unique strategies (Competition and Comparison loaded into one factor as did Self-monitoring and Suggestion) thereby reducing strategies to eight.
- Then Partial Least Square Structural Equation Modeling (PLS-SEM) to create models showing efficacy of eight persuasive strategies for each of seven gamer types.
- Finally, pairwise comparison approach [Chin 2000] to establish that models differed across gamer types.
- Results showed different gamer types motivated by different strategies: create structural equation model of strength of motivation of different players (Table 1).
 - o Significant positive β = gamer type motivated by strategy;
 - o Negative β value = gamer type demotivated by strategy;
 - o No β value = gamer type neither motivated nor demotivated by strategy.
- Achievers motivated by Reward. Conquerors motivated by Competition.

- Intention: allow game designers to use results to guide design choices.

EXPERIMENTAL VALIDATION:

Model-driven Persuasive Game Design:

- JunkFood Aliens: To validate model, implemented model-driven game to promote healthy eating based on Space Invaders - conflict between healthy and unhealthy eating.
 - Players = healthy eating hero on mission to search for fruits and vegetables and save planet from invasion of junk foods.
 - Players consume healthy foods by shooting them
 - Gain strength by collecting hearts
 - Players progressing through levels with increasing difficulty
- Simple game design
- Model proposed:
 - Conquerors – i.e., challenge-oriented players enjoy struggling against impossibly difficult foes before eventually beating other players [Nacke et al. 2013] – respond to Competition and Comparison but not to Reward
 - Achievers – i.e., goal-oriented players motivated by working towards completion of long-term goals [Nacke et al. 2013] – respond to Reward, but not Competition and Comparison.
- 2 versions of JunkFood Aliens:
 - **JFA-R** – Reward - display current point score and awarded five badges – Fan, Captain, Legend, King, and Hero. Logarithmic - quickly initially, but more work as player advanced
 - **JFA-C** - Comparison & Competition. Simulated leaderboard [Orji 2014; Bowey et al. 2015] compared performance of actual player and 4 imaginary ones. Leaderboard generated reasonable comparison scores, using the real player's score as a reference. [Orji 2014].
 - R and C easily mapped to 2 games mechanics: points, levels and badges (Reward) and leaderboards (Comparison and Competition).

Model-driven Persuasive Game Evaluation:

- Large-scale evaluation of 2 versions on 2 distinct types – Achievers and Conquerors.
 - Most common types [Bartle 1996; Nacke et al., 2013]
 - Achievers and Conquerors show distinct perceptions of most strategies.
- Study design:
 - Online – 1hr
 - 2 (Gamer type: Achiever, Conqueror) by 2 (Intervention Type: Reward, Comparison) between-subjects design.
 - Participants completed:
 1. BrainHex survey (28 items) [Nacke et al. 2013]
 2. demographic survey
 3. 3 scales based on theory of planned behaviour [Ajzen 2006] to assess
 - attitude toward healthy eating (7 items),
 - healthy eating intention (7 items),
 - self-efficacy towards healthy eating (5 items).

- Internal consistency - Cronbach's alpha values above 0.70.
 - Randomly-assigned to 1 of 2 intervention types.
 - Played game for 20 min - intervention displayed each minute
 - Game interrupted each minute with Reward-based or Comparison-based intervention which were either dismissed or written down by player
 1. To complete, participants had to record at least 20 different appearances of intervention page.
 - Participants play game as long as was required.
 - Score submitted (to ensure attention).
 - Participants completed same scales assessing healthy eating attitude, self-efficacy, and intention and also assessed game play experience using intrinsic motivation inventory (14 items) –validated scale for measuring enjoyment, invested effort, perceived competence, and tension [Ryan et al. 2006].
 - 2 mean values for their attitude, self-efficacy, and intention: baseline value and post-intervention attitude
 - Two pilot studies conducted.
 1. (N=40) tested validity of study instrument.
 2. (N=4) participants observed while played game and completed survey using thinkaloud
- Data Collection and Filtering:
 - Participants recruited online through crowd-sourcing (Amazon's Mechanical Turk (AMT)) using Mason and Suri [Mason and Suri 2012], including:
 - captcha and open-ended questions that require intelligence
 - participants could respond to study once
 - identifications examined – no duplicate responses received.
 - attention questions to ensure participants actively considering answers.
 - AMT to access large / diverse sample - valid tool for conducting user studies [Kittur et al. 2008], and games research [Orji et al. 2017; Orji et al. 2014; Birk, Atkins, et al. 2016; Depping and Mandryk 2017]
- Participants:
 1. 901 responses collected - 335 responses retained (removing types other than Achiever / Conqueror)
 2. Removed participants who did not correctly answer attention determining questions [Mason and Suri 2012].
 3. Participants at least 18 years of age, all computer or video game players, which ensured accurate mapping to types.
 4. Randomly under-sampling to equalize group distribution and gender balance, 272 responses included in analysis; 117 f, 155 m - 136 Achiever, 136 Conqueror.

DATA ANALYSIS:

- Goal: examine and compare persuasiveness of tailored game and contra-tailored game with respect to ability to promote changes in healthy eating attitude, self-efficacy, and intention.
- Also if play experience mediated effect of tailoring on efficacy of persuasive games.

1. Examine scales for internal consistency using reliability analysis. Given positive results, data found suitable to proceed with analysis
2. Validating data for assumptions of ANOVA, conducted Repeated-Measures Multivariate Analysis of Variance (RM-MANOVA) with time (baseline, postplay) as within-subjects factor and gamer type (Achiever, Conqueror) and Intervention Type (Competition, Reward) as between-subjects factors on attitude, intention, and self efficacy toward healthy eating.
3. Following findings of significant effects, performed planned pairwise comparison, using Bonferroni method for adjusting DOF for multiple comparisons, to determine groups that significantly differ from each other.
4. To determine whether efficacy of persuasive games mediated by player experience, conducted parallel mediation regression models of tailoring (tailored, contra-tailored) on attitude change, intention change, and self-efficacy change, with experienced enjoyment, invested effort, perceived competence, and tension as mediators while controlling for gender.

RESULTS:

Scales demonstrated internal consistency, with Cronbach's alpha values above 0.70.

Results showed tailoring persuasive strategy to gamer type according to predictive models produced intervention that yielded improved attitude, intention and self-efficacy toward healthy eating.

- **Gamer Type.** RM-MANOVA with time (baseline, post-play) as a within-subjects factor and gamer type (Achievers, Conquerors) and Intervention Type (Competition, Reward) as between-subjects' factors on attitude, intention, and self-efficacy toward healthy eating show there was no main effect of gamer type on any measure.
 - Achievers did not rate their attitude, intention, or self-efficacy differently overall than Conquerors - no group-level differences in the ratings.
- **Intervention Type.** No main effect of Intervention Type on any measure – attitude, intention, and self-efficacy, suggesting that random assignment of participants to the two intervention types did not yield groups who rated their attitude, intention, or self-efficacy differently overall.
 - Random assignment to the experimental conditions was effective and did not produce bias.
- **Time by Intervention.** Efficacy of interventions over time, no significant interaction between time (pre, post) and intervention type - when we do not consider gamer type, there is no significant difference between how a Reward-based or Competition-based intervention affects attitude, intention or efficacy.
 - Without considering gamer type, results would suggest Reward and Competition strategies are not different in their effectiveness;
 - Considering 3-way interaction with gamer type shows otherwise.
- **3-way Interaction between Gamer Type, Intervention Type, and Time.** Shows beneficial effects of tailoring persuasive games. Model predicted Achievers respond only to Reward and Conquerors respond only to Competition. Results show there are significant interactions between Gamer type, Intervention type, and Time for all the three measures – attitude, self efficacy, and intention (see Table II).
 - Gamer type must be considered when evaluating persuasiveness of a game for change.
 - Pairwise comparison shows that for:
 - Achievers. Influenced by Reward strategy but not Competition & Comparison for all measures. Playing JFA-R motivated increase in all measures (Attitude: $p < .001$; Intention: $p < .001$; Efficacy: $p < .001$),

- whereas playing JFA-C led to no significant change in all measures (Attitude: $p=.691$; Intention: $p=.094$; Efficacy: $p=.573$).
- Conquerors. Influenced by Competition strategy but not Reward strategy. Playing JFA-C motivated increase in all measures (Attitude: $p<.001$; Intention: $p<.001$; Efficacy: $p<.001$), whereas playing JFA-R led to no significant change in all measures (Attitude: $p=.204$; Intention: $p=.099$; Efficacy: $p=.672$).
- Unclear whether tailored games for change more effective because persuasive strategies employed more effective or whether participants more motivated because they had better play experience when playing tailored version.
 - **Play experience does not mediate how tailoring improves the persuasiveness of a game for change, and is not the casual path of increased efficacy of tailored games for change**
 - Conducted parallel mediation regression models [Hayes 2013] of tailoring (tailored, contra-tailored) on attitude change, intention change, and self-efficacy change, with experienced enjoyment, invested effort, perceived competence, and tension as mediators and while controlling for gender.
 1. Total effect of tailoring on attitude change, intention change, and self-efficacy change remained significant direct effect even after play experience measures (enjoyment, competence, effort, and tension) included as mediators in model.
 2. Although tailoring an intervention increased experienced enjoyment and perceived competence, bootstrapped confidence intervals for all mediators in all models include zero [Hayes 2013], suggesting no mediation of enjoyment, competence, effort, or tension on how tailoring an intervention improves attitude, intention and self-efficacy; furthermore, the p-value for all normal theory tests were non-significant (all $p>0.2$).

DISCUSSION AND SUMMARY

- Very tempting to assume persuasive strategies in games produce expected outcome of motivating desirable behavior change irrespective of target audience or user type.
- Investigating hypothesis that tailoring persuasive strategies employed in games for change to gamer type increases their effectiveness at motivating desired behaviour change.
 - Demonstrated different gamer types motivated by different strategies and developed models for tailoring persuasive strategies in design of games for change to gamer types.
 - Models show Achievers motivated by Reward but not Competition, whereas Conquerors are motivated by Competition but not Reward.
 - To validate results of model in experiment, implemented 2 versions of model-driven game promoting healthy eating
 - Results suggest for games to achieve objective of promoting desirable behaviour change, necessary to tailor games using personalization models of how different gamer types respond to different persuasive strategies.

Relative and Comparative Efficacy of Persuasive Strategies

- Considering gamer types shows strategies vary in efficacy depending on gamer type under consideration.
 - Explains why many interventions employing one-size-fits-all approach record varying degrees of success [Kaptein et al. 2012].

- Argued that using Reward as an incentive to change behavior has the potential of redirecting intention of a activity [Colineau and Paris 2011].
 - [Gneezy and Rustichini 2000] showed introduction of tangible compensation did undermine performance, especially if Reward considered small.
 - [Birk, Mandryk, et al. 2016] suggests rewarding players can demotivate behavior change.
- Work shows that rewards can be effective if well matched to profile of player in games.
 - E.g. for Achievers, but not for Conquerors

Using Pop-ups to Capture Attention

- Game designers battle with how to manage players' attention
- JFA demonstrates one possible way - Contrary to common game design practices; however, it ensures players pay attention to persuasive information contained in intervention page.
- Results of study show approach successful at focusing attention to persuasive message and made players reflect on message in general.
 - However, participants mixed reactions - Some liked that interruptions gave opportunity to review performance and re-strategize.
 - On other hand, interrupting gameplay annoyed some players
- To balance tension between attention and overwhelming them is to display pop-ups less frequently or display at time it will cause less interruption.

Design Implications for Games for Change

- *Games for Change Designers Do Not Have to Employ Multiple Strategies to Make Their Games Effective*
 - Common for designers to incorporate multiple strategies with hope 1+ of strategies suitable
 - Result is overly complex game that may overwhelm users [Khaled 2008].
 - Another problem: difficult to evaluate which strategy worked.
 - Results show that using single strategy led to effective game.
 - Multiple strategies effectiveness still unclear
 - According to [Kaptein 2012], leads to reduced persuasive effect.
 - In absence of models greater probability of using combination of inappropriate strategies.
 - Research found even in situations where 2+ strategies equally effective, "persuasion does not always add up" [Kaptein 2012].
 - Simple game design to reduce interactions between persuasive rhetoric and game narrative - future work should investigate interaction between the persuasive rhetoric of game and persuasive strategy.
 - Possible that different types of games yield different advantages of tailoring.
- *Games for Change Can Be Tailored by Adapting Only the Strategies Employed*
 - Drawbacks to tailoring is cost adapting games for change for each user type.
 - JFA shows game designers do not have to design each game version from scratch to adapt to the target audience.
 - Existing games can be adapted to suit target audience by incorporating appropriate persuasive strategies

LIMITATIONS AND FUTURE WORK:

1. Research limited to promoting attitude, intention, and self-efficacy change toward healthy eating and should be extended to other domains.

- Measure attitude change, intention to change, and self-efficacy to change - precursors to actual behaviour change; however, future work should investigate whether the increased efficacy of tailored games for change translates into differences in behaviour.
- 2. Participants recruited from AMT - not all AMT participants psychologically engaged / motivated by compensation.
 - Results may not necessarily generalize; future research should compare with participants recruited from other domains (intrinsically motivated).
 - Investigate for possible domain dependency of personalization models by applying them in designing games for change targeting other domains.
- 3. Effectiveness of tailoring and validity of our personalization model using only two gamer types (Achievers and Conquerors) out of seven BrainHex types and two persuasive strategies (Competition and Reward).
- 4. Comparing game designed using single strategy versus multiple would extend existing knowledge in this research area.
- 5. If game performance mediates effect of tailoring on effectiveness of games for change.
- 6. Automatically determine player personality type during the game

CONCLUSIONS:

- Dynamic selection of appropriate persuasive strategies will increase efficacy of games
- *One size does not fit all* –tailoring will increase effectiveness
- Although tailoring improved play experience, play experience (enjoyment, competence, effort, or tension) does not mediate how tailoring an intervention improved the persuasiveness of a game for change, with respect to attitude, intention and self-efficacy change.
- Strategies vary comparative efficacy depending on gamer type.

Video: https://www.youtube.com/watch?v=T0nPw2WrO_Q&list=PLqhXYFYmZ-VeQedZeRi7N4jrBxCycsxbR&index=7

- *One size doesn't fit all when designing games to change behaviour*
- *Does tailoring games to target the user's personality type increase their efficacy at motivating behaviour change?*
- *Are the beneficial effects of tailoring mediated by an improved play experience?*
- *99% of adolescent boys play digital games regularly. 94% of adolescent girls play digital games regularly*
 - *Seeing games developed for purposes other than entertainment at increasing pace*
- *Games for change are effective at motivating behavioural change and actions beneficial to them and their community*
 - *E.g. Health games to manage addictive diets, maintain effective exercise and activities, manage disease. Squire's Quest 2 game aimed to increase consumption of fruit, juice and vegetables to reduce diseases related to diet*

- *Main problem – adopting “one size fits all” approach does not work – this works against the performance of users of certain personality types*
 - *Using a leader board could motivate competitive players but not other personality types*
- *How to tailor for change?*
 - *Study of 1108 participants in initial work explored relationship between type of personality (Achiever, Conqueror, Daredevil, Mastermind, Seeker, Socialiser, Supervisor) and type of persuasive strategies (Competition and Comparison, Cooperation, Customisation, Personalisation, Praise, Self-Monitoring, Simulation, Reward)*
 - *Developed models to compare how different user types responded to different strategies*
 - *Numbers are the coefficient from model – if significant a number exists in the cell, higher number = higher weight*
 - *Empty cell means strategy won't motivate player of that type to change their behaviour*
 - *Negative value means demotivation*
 - *Detail (Orji 2014)*
 - *Statistically significant difference in responses to strategies for each type of player*
 - *Now question is how to employ results in games for change design?*
 - *Designed 2 model-driven games targeting achievers and conquerors*
 - *Two of the common gamer types, which show a distinct difference in response to strategies shown by Orji 2014 – interesting types to consider*
 - *Achievers = rewards, Conquerors = competition.*
 - Complementary effects on each respective gamer type.*
 - *“Junk Food Aliens” game designed – competition vs reward versions – cross-platform game based on the classical space invader game – twist in narrative.*
 - *Game panel designed to simulate conflicting impact of healthy eating and struggle people face between healthy and unhealthy foods.*
 - *Both versions: Player's avatars lose health and eventually dies when player chooses unhealthy foods*

- *Difference = competition version has competing with other players whereas in the reward version they are rewarded on their performance.*
 - *Reward = badges based on performance*
 - *Competition = performance shown relative to other players of the game.*
- *To evaluate efficacy a large scale randomised controlled study took place with 272 game players after the game was deployed – 50% achiever, 50% conqueror.*
 - *177 / 155 F/M*
 - *Evaluated efficacy of game using pre-test and post-test – measure behaviours before and after playing*
 - *2 conditions – each gamer type split into 2 groups and randomly assigned 1 of 2 conditions –*
 - *tailored (TC) – played game with strategy they deemed persuasive (Achievers = rewards, Conquerors = competition)*
 - *contra-tailored condition CTC - played game with strategy they did not deem persuasive (Achievers = competition, Conquerors = reward)*
 - *50 / 50 not done by recruitment but by scaling down total number of players from over 800 – controlling for gender randomly*
 - *To determine player type, automated scale when players respond to questions based on their playing attitudes n first playing the game*
 - *Measure of efficacy to promote healthy eating – **attitude, self-efficacy, intention** (3 direct predictors of behaviour)*
 - *If model true, then competition should be more effective for conquerors and reward should be more effective for achievers playing game. This is the result from measuring mean attitude change before and after –*
 - *achievers playing the reward version showed heightened positive change in attitude towards healthy eating, and increased mean negative attitude after playing competition version*

- conquerors playing the competition version showed heightened positive change in attitude towards healthy eating, and increased mean negative attitude after playing reward version
 - Similar for self-efficacy and intention – tailored version more effective than contra-tailored.
- CTC led to no change in self-efficacy, and negative mean change in attitude for achievers – using inappropriate persuasive technique can be detrimental to behavioural change
- *Still unclear:*
 - Were the tailored conditions more effective because the strategies themselves were more effective?
 - Were the tailored conditions more effective because the players had a better play experience of playing games using that persuasive device?
- *To answer these questions, it was investigated whether play experience mediates the effects of tailoring games for change.*
 - *To answer, conducted parallel mediation modelling of tailoring on attitude, intention and self-efficacy change with play experience on the mediator.*
 - Results from mediation analysis show there is a total effect of tailoring on attitude change ($\beta = .721$). Direct effect remains significant even after including play experience as a mediator in the model ($\beta = .662$).
 - Similar results for intention and self-efficacy change. Effects significant even after including play experience as a mediator in the model.
- *Conclusions:*
 - There is value in tailoring games for change – heightened positive changes in all measures.
 - CTC led to no significant change - tend to lead to mean negative change in attitude of achievers.
 - Play experience doesn't mediate the effects of tailoring games for change
- Future work:

- Self-selection of player type vs. detected – gamer chooses a strategy they think benefits them – customisation
- Understanding player type from their in-game activities – open to work
- If we have multiple strategies at a time – do the cumulative effects produce a positive or negative result?
- Test more combinations of strategies on gamer types.

<https://dl.acm.org/citation.cfm?doid=3149825.3119929>

500 words: Summarising contribution of article – (e.g. new ideas, what do we learn?) include references to neighbouring literature.

500 words: Assess extent to which work reported justifies articles' conclusions.

500 words: Outline further work you consider might be done to build on article. Begin by future work authors outline but try to add your own suggestions.

Essay 2: Exploring Interactions with Physically Dynamic Bar Charts [2015]

Topic: Information Visualisation - How should complex data best be presented to decision makers? The field of Information Visualisation ('InfoVis') has grown rapidly in recent years as designers of interactive software have targetted this issue. There is important background research in Exploratory Statistics as well as in the Psychology of Decision Making (especially multi-dimensional decision making). Additionally, there are plenty of interesting theory-based research products - see for example the edited collection by Card, Mackinlay and Shneiderman; and more recent journal articles.

Abstract: Visualizations such as bar charts help users reason about data, but are mostly screen-based, rarely physical, and almost never physical and dynamic. This paper investigates the role of physically dynamic bar charts and evaluates new interactions for exploring and working with datasets rendered in dynamic physical form. To facilitate our exploration we constructed a 10x10 interactive bar chart and designed interactions that supported fundamental visualisation tasks, specifically; annotation, filtering, organization, and navigation. The interactions were evaluated in a user study with 17 participants. Our findings identify the preferred methods of working with the data for each task i.e. directly tapping rows to hide bars, highlight the strengths and limitations of working with physical data, and discuss the challenges of integrating the proposed interactions together into a larger data exploration system. In general, physical interactions were intuitive, informative, and enjoyable, paving the way for new explorations in physical data visualizations.

Video:

https://www.youtube.com/watch?v=oMWTn_h0NqE&index=4&list=PLqhXYFYmZ-VeDVQtk8euBKIJS97KGzW9a

- **Research: How people might interact with physical representations of data such as a bar chart?**
 - Key interaction techniques and the feasibility of a physical dynamic bar chart
- Combine InfoVis with shape-changing display technology – EMERGE (10x10 physically dynamic tool)
 - Picked tasks from Heer and Shneiderman's taxonomy for visual data analysis – covers a wide range of tasks.
 - No idea how people interact with physical charts so a selection made of fundamental tasks – Filtering, Navigation, Annotation, Organisation.
- Architecture – slider panels, mechanical linkages, plastic rods, LED strips, Kinect and projector
- User study – 17 participants (6f). For each task (Filtering, Navigation, Annotation, Organisation)
 - User proposed interaction: Before showing users tool, asked how they wanted to achieve tasks
 - Asked them to complete tasks like “select the year a country had the highest electricity consumption”.
 - Demonstration: Then gave demo of tool
 - Actual interaction: Tasks using EMERGE tool
 - Questionnaire: Getting feedback – rate interactions they carried out. Semi-structured discussion.
- Findings:
 - Annotation: (Selecting or marking data points) –
 - Point: Point on axes, then selects by cross-hairs the point to select to annotate.
 - Pull: Direct pull of data point bar.
 - Press: Direct press of data point bar.
 - User proposed: **Press**
 - Actual interaction: **Press**
 - Need visual feedback (selected bar stays illuminated) – pressing most natural.
 - Filtering: (Hiding data to compare values and trends) –
 - Swipe-away: Swipe on row axis to hide them.
 - Manual (full) press: Manually push down individual bars to hide them.
 - Assisted (partial) press: Manually push down individual bars part of the way to hide them.
 - Press shortcut: Manually push down individual bar at end of row to hide entire row.
 - Press to compare: Manually push down individual bar at end of 2 rows to hide all rows besides the ones selected.
 - User proposed: **Touch / gesture interaction**
 - Actual interaction: **Press shortcut and press-to-compare**
 - Combine hiding and keeping of rows – pressing almost all rows just to see one is very repetitive.
 - Organisation: (Re-arrange data by moving rows)

- Instant drag: Drag on axis to shift row (rows swap and click into place after gesture).
 - Transition drag: Drag on axis to shift row (rows are shown to move where finger points and click into place after gesture).
 - Instant press: Press on two rows simultaneously on axis to swap them (rows swap and click into place after gesture).
 - Transition press: Press on two rows simultaneously on axis to swap them (rows are shown to move and click into place after gesture).
 - User proposed: **Drag projected label**
 - Actual interaction: **Drag projected label**
 - Transitions unnecessary
 - Mistakes embarrassing if used for presentations – wait for transition
- Navigation: (Go through larger data sets – e.g. identifying trends over time). As it's a 10x10 interface, how does navigation work.
 - Scrollbar: Drag bar across to change (continuous or discrete) data.
 - Touch to scroll: Fine grained - Use touch buttons to change (continuous or discrete) data.
 - Press to scroll: Fine grained - touch bars to change (continuous or discrete) data by 1 row.
 - Paging: pressing on bars to move left and right (blocks of 10).
 - User proposed: **Swipe to scroll**
 - Actual interaction: **Swipe to scroll**
 - Show values whilst scrolling
- **Physical / gestural interactions have benefits / shortcomings**
 - Larger actions suited to touch-gesture interactions (e.g. organisation).
 - Smaller actions suited to physical interactions (e.g. annotation).
 - Interacting with data points feasible (not intrusive) – not perceived to interfere with data. People liked pressing bars.
 - *Physical = annotation and filtering*
 - *Gestural = organisation and navigation*
- **Combine fine-grained and coarse-grained control to minimise repetition**
 - E.g. filtering (hiding / keeping rows)
 - E.g. navigation (trends vs specific ranges)
- **Perceptions of physical bar chart**
 - Influence from touch-screen style interactions – smartphones
 - Movement / behaviour around the display – physical position / posture
 - Surprise factor from actuation speed – too fast is surprising, too slow is frustrating
- **Limitations and further work:**
 - Scoped to fundamental tasks – limited interaction techniques
 - One possible implementation for bar charts
 - Exclusion of vertical axis (z-axis) data – only X-Y-Z data considered.
 - Combining techniques – more physical exploration
 - How people use their body to interact with data.
 - Navigation of virtual environments in a similar way (VR)
 - Novelty of shape changing display

- With more people – desire to prod bars. Interesting to observe problem solving in groups.
- How people interpret height values
- **Summary:**
 - Groundwork for more complex interactions
 - Participants successfully identified trends / extremes
 - Feasibility of physical interactions (e.g. data points)

<https://dl.acm.org/citation.cfm?doid=2702123.2702604>

500 words: Summarising contribution of article – (e.g. new ideas, what do we learn?) include references to neighbouring literature.

500 words: Assess extent to which work reported justifies articles' conclusions.

500 words: Outline further work you consider might be done to build on article. Begin by future work authors outline but try to add your own suggestions.

ABSTRACT

- Visualizations (e.g. bar charts):
 - help users reason about data
 - mostly screen-based
 - rarely physical
 - almost never physical / dynamic.
- Investigates role of physically dynamic bar charts and evaluates new interactions for working with datasets in dynamic physical form e.g. 10×10 interactive bar chart.
- Designed interactions supporting fundamental visualisation tasks:
 - annotation
 - navigation,
 - filtering,
 - comparison,
 - organization,
 - sorting.
- Evaluated in user study - 17 participants.
 - Preferred methods of working with data for each task
 - strengths and limitations of working with physical data
 - challenges of integrating proposed interactions together into larger system.
- Physical interactions intuitive, informative, enjoyable

INTRODUCTION

- Effective visualizations - “use vision to think” [3] - improve reasoning.
 - Increase effectiveness of processing information
 - Transform to visual structures that leverage ability to detect patterns.
- Current visualizations optimised for 2D screens
- InfoVis community designing 3D visualizations for physical devices / non-traditional inputs [15, 17, 18, 23].
- Work compared 3D physical charts with 3D onscreen visualizations [16]
 - rich qualities of physical objects important in data inspection

- Huron et al. [13] - how people construct, manipulate, update visualizations using tangible tokens.
 - Other examples
 - data sculptures [1]
 - tactile cartographic maps [27].
- Main drawback of current physical visualizations = inert
 - fabricated (i.e. laser cut [15], 3D printed [3], constructed from passive building blocks [13])
 - thus disconnected from data-source once constructed.
- Shapechanging interfaces (i.e. Relief [22], inFORM [6]) have potential to alleviate these drawbacks.
- Community lacks understanding of how data interacted with to achieve intuitive data exploration with physically dynamic displays.
- Paper = first exploration of user interactions with data using our custom dynamic bar chart EMERGE
 - self-actuating rods capable of RGB colour output
 - touch detection for pushing and pulling of data itself,
 - traditional touch detection on surrounding surface.
- To set design guidelines for physically dynamic data, study (17 participants) investigated fundamental interaction tasks: annotation, filtering, organisation, and navigation.
- Explore
 - direct manipulation of data points (e.g. pulling)
 - gestures on projected axis labels (e.g. moving rows).
- Baseline for more complex and diverse interaction techniques.
- **Key contributions:**
 - Identification / design of 14 baseline interaction techniques with physically dynamic bar charts,
 - User study evaluating interactions (which preferred / effective)
 - Important design considerations / challenges for physically dynamic visualizations.

RELATED WORK

- 'Physicalizations' [17] informed:
 - visualization [15, 25]
 - tangible and shape-changing interfaces [22].
- Few papers used dynamic, physical interfaces to visualize data – no study has investigated possibilities and usefulness of interactions for such interfaces.
- Research questions:

Static physical visualisations

- Physical visualizations extend benefits of visualizations (active perception skills, sensory information + visual sense).
- Jansen and Dragicevic [16] list of physical visualizations includes 6+m yo.

- <http://dataphys.org/list> - Show quantity in physical form (number = physical height).
- Paneels and Roberts [26] - haptic data visualization (audio, texture/friction, enclosures) to show quantity.
- Previous research examined: efficiency of physical visualisation [15], approaches for physical visualizations design [35].
 - Jansen et al. [15] - 3D printed physical visualizations improved users' efficiency at information retrieval tasks (physical touch and visual realism).
 - Stusak and Aslan [35] - examined physical prototypes - can support analytical tasks through mature design (importance of stability and affordances)
- Physical visualizations increase accessibility of data to blind or low-vision users [3, 7, 19, 24]. e.g.
 - tactile pin arrays to show graphics [39],
 - VizTouch [3] - blind users 3D print visualizations line graphs
 - tactile maps [27] show cartographic data using physical properties (physical height corresponds to elevation of the terrain).
- Others have artistic aims:
 - 'data sculptures' [1] = visual artefacts that communicate information (jewellery that shows internet connection rates).
 - Khot et al. [30] – Sweatatoms - 3D modelling / printing system that turns activity patterns in sports into 3D objects that support reflection and aesthetic pleasure.
 - Stusak et al's 'activity sculptures' artistically visualised running activity for discussion and reflection [36].
- Physical visualizations' range of benefits over visual counterparts [16, 25, 38].
 1. Physical objects can be manipulated more directly than mouse / touch screens [16].
 2. Interplay (vision + touch) facilitates cognition [15].
 3. Physical modality - range of new interaction possibilities
- Useful + attractive BUT must be fabricated before use.
- Modifications limited once created - computational / interactive benefits of screen-based visualizations lost.

Dynamic physical visualisations

- Work into TUIs + shape-changing interfaces attempts to address static disadvantages by showing non-static data.
- Typical shape displays have physical pixels (binary (on/off) or continuous).
 - Physical pixels: motorized pins extrude from surface -- pneumatics [10] and shape-memory alloys [5] serve similar purpose. Extrusions mapped to data values. Resolution: (<10) pixels to inFORM's 900 motorized pins.

- Examples show tasks relating to visualization (bar chart data (Physical Charts), mathematical functions [6] and wind tunnel flow [21]).
 - Interactions use well-known input: direct touch, pulling and pushing [6, 23].
 - Sublimate [21],
 - Relief [22, 23] = free-hand gestures: hand gestures to translate, scale, and rotate 3D models.
 - Lumen [28],
 - Feelex [14],
 - Taxel [18],
 - inFORM [6] = remote gestural interaction and use of onsurface objects to control interactions such as menu selections.
 - Tilt Displays [1],
 - Physical Charts - <http://research.microsoft.com/enus/um/cambridge/projects/physicalcharts/>
- Free-hand gestures useful in many scenarios BUT
 - don't capitalise on haptic dimension (key benefit of physical visualizations)
 - don't support delicate manipulation of data - Jansen et al. [16].

Open questions for physically dynamic bar charts

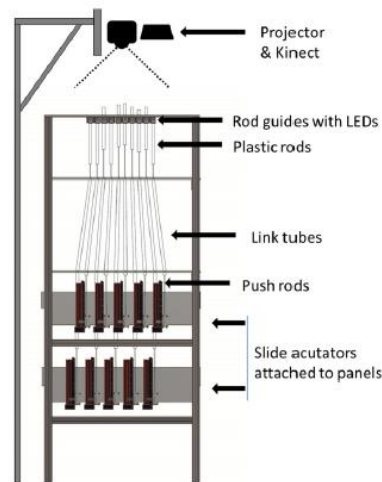
Previous research instigates several questions:

1. **How physically dynamic bar charts support tasks in visualization** – e.g. comparing values [2], gaining overview of dataset [33].
 - Previous work suggests multiple task models for use in visual data analysis [2, 11], but towards 2D data visualizations.
2. **Which interactions with physically dynamic bar charts are useful and usable.**
 - Contrasting previous work on static physical visualizations / data sculptures, support for user interaction crucial as ability of the interface to actuate itself.
 - Further, key aim of artefacts = help users think about data - focus is on visualizations, rather than control.
3. **Are useful interactions with static physical visualizations (e.g., [16]) transferrable to dynamic physical visualizations?**
 - Identifying useful interactions with physical dynamic graphs an open question, beyond straightforward use of touch, pushing/pulling, and mid-air gestures.

IMPLEMENTATION

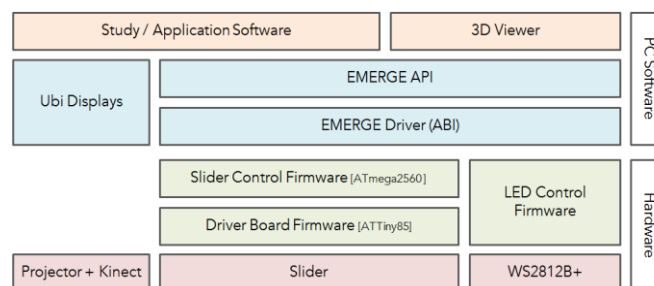
- Investigate data analysis tasks and interactions: EMERGE.
- Design follows that of inFORM system [6], differing through:
 - inclusion of LEDs,
 - hardware control architecture
 - software model.

Hardware:



- 10 × 10 array of actuated plastic rods linked to 100 motorized potentiometer sliders - 100mm travel length.
- Sliders (stacked in 2 layers) at bottom able to control plastic rods at top.
- Each rod illuminated by dedicated RGB LED - attached to guides to keep stable.
- Kinect and projector mounted to project information (axes, labels, controls) and detect touch.

Software:



- **Application layer:** multiple user study applications and 3D viewer/simulator.
 - Study applications in HTML5, hosted by UbiDisplays toolkit [9] to map projection and detect touch on surfaces.
- **Control firmware:** Arduino Mega2560, Arduino Uno.

APPROACH

- To reason about data exploration methods with dynamic physical visualizations, need to evaluate interactions.
- Novel methods exist for interacting with physical data
- Investigation based on Heer and Shneiderman's taxonomy [11] – commonly used visualization tasks = annotation, organization, filtering, and navigation.
- User study to elicit feedback about usefulness and usability
- Avoided early experimentation - others warned against approach [8, 12], given the immaturity of this area.

Task Structure

- Focus on 'physicalizing' bar charts:

- map to hardware setup
- used for previous studies on physicalizations due to low requirements for visualization literacy [15].
- Base exploration on Heer and Shneiderman's taxonomy for visual data analysis [11].
 - Structures interactive dynamics for visual analysis tasks into 3 high-level categories:
 - Data and View Specification,
 - View Manipulation
 - Process and Provenance.
 - Broken into sub-categories - utilized to derive relevant tasks in physical space.
- Task-sets adopted from Heer and Shneiderman's taxonomy in parentheses - Each task-set consists of multiple tasks/interactions.

Task	Overview	Interaction Techniques
Annotation (<i>Process & provenance</i>)	Selecting and marking individual data points.	Point, pull, press.
Filtering (<i>Data view & specification</i>)	Hiding and refining data for enhanced perception and comparison.	Swipe away, manual press, assisted press, press shortcut, and press to compare.
Organization (<i>View manipulation</i>)	Data arrangement by moving rows and columns.	Drag and drop with immediate transition and hide-all with transition, press with instant transition and hide-all with transition.
Navigation (<i>View manipulation</i>)	Controlling the view of large data sets.	Scroll, directional arrows, directional press, and paging.

- Some tasks excluded as not applicable to setup:
 - Coordinate from View Manipulation,
 - Concerns multiple views of data - experiment with 1 view
 - Share and Guide from Process and Provenance
 - Sharing involves exporting data (software-based)
 - Guiding leans towards helping users through workflows.
- Complex explorations excluded - need to understand basic interactions before exposing patterns and forming data models.
 - Sort and Derive from View Manipulation
- Record typically involves showing historical data (e.g. undo or redo) and forms larger 'data explorer' system, rather than fundamental interaction.

Participants

- 17 participants (6f). Mean age of 27.
- 0 experienced interacting with shapechanging displays.
- 2 previously seen demonstrations of shape-changing technology.
- ~40 minutes - compensated £8 for their time.

Materials

- EMERGE enables users to interact with actuating interface of LED-lit rods (representing bars of charts).

- Information e.g. labels projected around bars.

Procedure

- Participants individually introduced to EMERGE.
- Demographic questionnaire provided.
- Explored interactions for number of task-sets (annotation, organisation, filtering, navigation).
 - Some adapted from Jansen et al. [15] (e.g. physically selecting points of interest).
- Data sets from Jansen et al's [15] - included
 - HIV prevalence,
 - GDP percentage in exports,
 - annual electricity consumption,
 - UK rainfall dataset (required larger data set for Navigation).
- Data shown to users:
 - each row discerned by unique colour,
 - height of rod represents numerical value (y-axis).
- Study procedure – within-subjects:
 - 1- Followed guessability approach [40] - insights without influencing by demo. Ask how they could achieve task.
 - Sample dataset with interactivity disabled.
 - 2- Interaction techniques demonstrated - carried out to build familiarity.
 - 3- Task verbally given to elicit behaviours and feedback rather than accuracy.
- Ordering of task-sets / techniques counterbalanced to reduce influence
- After task, 5-point Likert questionnaire + comment collected on what useful / problematic.
- After session, short discussion for additional insights.
- Each session audio/video recorded.

EXPLORING PHYSICAL BAR CHART INTERACTIONS

- **Annotation:** select and mark data-points for later reference [11]. e.g.
 - documenting / returning to subsets of data,
 - communicate interesting observations.
- **Data set:** electricity consumption in 10 different countries (rows) between 1971 and 1998 (columns).
 - **Point:** 1 finger on projected row label, 1 on projected column label. All points dimmed except intersection. Selected year and country with highest electricity consumption.
 - **Pull:** Pull data point to select, dimming unselected data points. Selected year Qatar had highest electricity consumption.
 - **Press:** Press data point to select. Select year Iceland had lowest electricity consumption.

Feedback:

- Participants preferred press (Likert M: 4.29, SD: 0.99).
- Matched 16/17 initial perceptions – 1 preferred to pull column.

- *“favourite technique - simple. Actively selecting point, more than touching screen.”*
- 5 participants said visual feedback (dimming) allowed participants to distinguish selected point
- **Filtering:** Control items + focus by eliminating irrelevant data [33]. Useful for setup of physical bars.
 - Zacks et al. [41] - height estimates of printed bar charts on paper, distortions by neighbouring elements problematic – expected similar issues with physical bars. Clearing display of unneeded bars should aid users.
 - Data set: Export % of goods and services in 10 countries (rows) 1999 - 2008 (columns).
 - Swipe away: Swipe row label off edge of surface to hide. Hide 8 rows deemed irrelevant and state comparison between remaining 2.
 - Manual press: Push down all irrelevant points. Press points of 8 rows and compare GDP of remaining 2.
 - Assisted press: System detects pressure and hides pressed point. Hide row with highest exports percentage.
 - Press to compare: Pressing any point on 2 rows - hides other rows. Press and compare GDP of 2 selected countries.
 - Press shortcut: Point at beginning of each row acts as a control point. Once this data point is pressed, the remainder of the data in the row becomes hidden. Participants were asked to hide eight different rows and compare the GDP of the remaining two.

Feedback:

- 17 preferred to only tap row labels to hide irrelevant rows.
- Press shortcut technique preferred by most (M: 4, SD: 0.63). Regarded useful when smaller numbers of rows required to be hidden.
 - “best way - easy, weren't relying on touch screen, click column closest to name.”
- Press to compare preferred for smaller sets e.g. 2 rows (M: 3.94, SD: 1.06).
 - Cut down on repetitive selection
- Unlike initial perceptions to filter data (tapping projected labels), both highly rated techniques involved physical interaction.
 - Tradeoff - hiding small vs. large amounts of data.
- **Organization:** preferences for organizing data sets/points
 - Though Heer and Shneiderman's [11] taxonomy describe Organize in terms of multiple views, we look at organization within single view.
 - bring data closer
 - Data set: prevalence of HIV in 10 countries (rows) 1920-2012 (columns).
 - Drag and Drop: Touch-down + drag row label. Compare HIV prevalence between 2 countries by organizing rows.
 - Press to swap: Simultaneously select rows by tapping on column, and select destination by tapping on column in different row. Compare two countries side-by-side.

Also studied physical data transitions (i.e. points 'moving').

- Instant transition: New replaces old (bars immediately adjust).
- Hide-all and transition: Irrelevant rows hide at beginning of swap; selected and target rows swap values, other rows re-emerge.

Feedback:

- Study confirmed 17 initial preference to drag rows by projected labels. (M 3.88, SD: 1.22).
 - *"Easier to look at labels as opposed to interacting with columns directly rearranging."*
 - Hide-all and transition scored low in both techniques - preferred faster feedback.
 - 1 participant: in professional setting, accidentally selecting incorrect rows and waiting for transition embarrassing.
- **Navigation**: exploring data sets (e.g. geographic map overview, further details on subsets). Trends over time through data.
 - Limitations of shape-changing display = high cost to achieve higher resolution - 1-actuator-percolumn (e.g. inFORM [6]). Displays require mechanisms for large data sets.
 - Data set: Rainfall 10 different regions in UK (rows) 1920 - 2012 (columns).
 - Scrollbars: Projected on x-axis - tapping within moved dataset. All points shown (continuity) until selected position reached. Identify patterns between regions.
 - Directional Arrows: Projected arrows on surface. Tapping moved data by single column. Compare rainfall between 2 regions during a specific year.
 - Directional Press: All points on each half act as navigation mechanisms when pressed move one column. Compare rainfall between 2 regions during specific year.
 - Paging: All points on each half act as navigation mechanisms when pressed move 10 columns. Compare rainfall between 2 regions during specific year.

Feedback:

- Initially - 15/17 prefer navigating using scrollbar + swipe.
- 2 stated they prefer physical shift of columns left or right.
- Study: scrollbar preferred (Likert M: 4, SD: 1).
 - *"Scroll quicker for larger jumps"*
- Showing actual values whilst data scrolling useful to look at trends.
- Ratings lower for single-column navigation but participants stated it useful for fine-grained control.
- Necessary to support continuous and fine-grained data navigation.

DISCUSSION

User study feedback + behaviours indicate how bar charts effectively combined with shape-changing technology.

Gestural vs. Physical Interaction

- Techniques = directly touching data (plastic rods) + gestures for manipulation (e.g. swiping).
 - No clear difference in preferences (Likert scale)
 - Based on context - press when annotating, larger gestures for organization.
- Positive feedback from physical interactions provides freedom to integrate types of interactions.

Combining Interaction Modalities

- Switching between overview and fine interaction highly useful.
 - e.g. scrolling in navigation - participants noticed distinction over time.
 - 1 participant would like to expand point showing rainfall by year and region into months that make up yearly value.
 - e.g. filtering combining press to compare with press shortcut to hide a row.

Effect of Preconceptions

- Prevalence of touch-screen devices meant initial preferences consisted of swipe, drag or taps on projected labels as familiar and intuitive.
- For filtering, participants initially suggested using swipe or tapping on row label.
 - After exploring direct touch interactions, opinions shifted.
- Designers should capitalize on familiarity in shape-changing displays but also realize physical interactions can expand interaction space.

User Reactions

- Shape-changing displays uncommon so initial approach/reaction important.
 - Nearly all participants surprised/startled by actuation + noise.
 - 3/17 moved around system to carry out interactions.
 - 1 moved to side of display to press down on 2 rows to compare (filtering).
 - Another bent down to align themselves and select highest (annotation).
- Movement likely reduced by fixed label alignment - orientation could be adjusted based on position.

Limitations and Technological Challenges

- **Focus on fundamental tasks + limited interaction techniques.**
 - Further studies explore should interaction space (actions, gestures, tasks and techniques).
- **10×10 data points so limited data presented.**
 - Scalability of interactions requires further investigation.
 - Higher resolution might afford different types of interactions (pagination might suffice)
- **Excluded vertical axis data - difficult to anticipate how this might change user interactions and behaviours.**
- Technological challenges:
 - Actuation speed
 - Spacing for plastic rods
 - Size of entire setup.

- Study showed almost all participants hesitant to interact with system due to speed of actuation or noise of actuators
- Large actuator size forced increase of height to reduce angles and enable smooth actuation.

Generalizability and Future Directions

- User study identified preferred baseline interactions for manipulation tasks
 - Smaller interactions (annotation) afforded physical interaction,
 - Larger motions (organization) afforded touch-screen swipe.
- Further work:
 - Data manipulation with external objects,
 - Multi-finger input,
 - Pressing over time.
 - Complex task explorations from taxonomy - undo/redo, different filtering (e.g. thresholding)
 - Combining interactions
 - Controlled studies with performance metrics (e.g. task completion times, accuracy)

CONCLUSION

- Key objective of paper: uncover how physically dynamic bar charts support data analysis-based interaction techniques.
- Study provides initial insight into physical data exploration - 14 interaction techniques formed part of 4 task-sets: annotation, filtering, organization, and navigation.
- Combining interaction modalities, incorporating familiar interactions (i.e. touch-screens).
- Groundwork for future investigation into physically dynamic data visualizations.