Communication in the Changing Dyadic Interaction of Diverse Players

Mark Rice
Institute for Infocomm Research
A*STAR
Singapore, 138632
mdrice@i2r.a-star.edu.sg

Jamie Ng
Institute for Infocomm Research
A*STAR
Singapore, 138632
jamie@i2r.a-star.edu.sg

Hong Huei Tay
Institute for Infocomm Research
A*STAR
Singapore, 138632
tayhh@i2r.a-star.edu.sg

Ranieri Koh
Institute for Infocomm Research
A*STAR
Singapore, 138632
ranieri.koh@i2r.a-star.edu.sg

Abstract
In this paper, we present the findings of a two month exploratory game study in which we compared the verbal and non-verbal communication practices of two independent groups of older adults. Among other factors, these groups differed in their education, technology literacy and physical functioning. Through observational measurements, we outline significant differences and trends in players' paired interaction, which progressively changed through prolonged exposure to the game. By comparing player performance both within and between groups, we raise questions and provide some insights as to how differences in the backgrounds of older players can influence dyadic interaction in collocated play.

Author Keywords
Older adults; socio-economic; verbal communication; physical directives; graphical silhouette; Kinect

ACM Classification Keywords
K.8.0 Personal Computing: General – *Games*

Introduction
The heterogeneity of older adults demonstrates a potential array of interests and opportunities for digital game design. In an ageing population, the rate of physiological decline is known to vary on an individual level, contributed by biological and social factors [18].

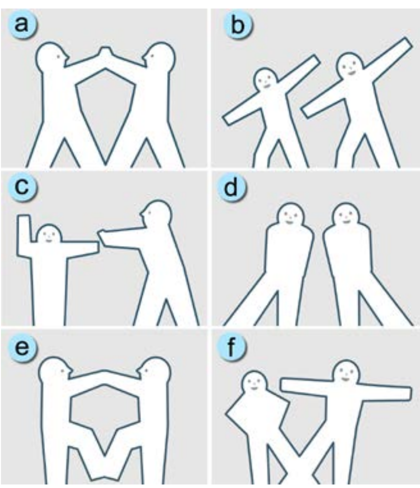

Figure 1. Examples of the body templates incorporated in the game - (**a-c**) wide base (two footed stances) and (**d-f**) narrow base (dominant or single leg stances).

Research by IJsselsteijn et al. [13] and Gerling et al. [11] have both reported on the need to understand age-related changes within game design. However, beyond clinical research, few known HCI game studies have compared independent groups of older players. In particular, there is a limited understanding to how digital games can meaningfully engage older adults from different socio-economic or geographical backgrounds.

Lifestyle and the regional characteristics of older adults have been found to be a strong predictor of self-rated physical health and quality of life [23]. In addition, variations in education and personal income are known to affect one's ability to maintain cognitive functioning in old age [18], and influence technology adoption among older adults [21]. Alternatively, while game studies have investigated socio-economic differences in young players [e.g. see 1], understanding how variations in social status translate into multiplayer gameplay and pathways for game research in older adults remains poorly understood. Subsequently, we see this as an important issue in Asian countries like Singapore, where an ageing population consists of multiple ethnic and dialect groups.

In this paper, we present a longitudinal evaluation of a prototype game with two separate groups of older adults. These groups vary in their education, language, technology literacy and physical functioning. Motivated to understand the extent player relationships might vary across these groups, a full-body gesture-based game using the Microsoft Kinect was developed primarily to explore the communication between pairs of older players. The results indicate that players exhibit significant differences and trends in their collaborative engagement. As such, we believe a key contribution of this work is to understand the variability between older players, and how interactional roles can dynamically change over time. Subsequently, we hope these findings will draw interest and further debate from the HCI community.

Communication practices

Of the various factors affecting gameplay performance, we focus on the communication aspect. Communication is fundamental to understanding social interaction in digital games, and is deeply connected to the player's experience [8, 10]. In particular, understanding gameplay communication is a primary means of uncovering how players establish and maintain relationships. According to Drachen and Smith [10], communication between players serves as a functional means of requesting and sharing information to reach game goals. Defined as both verbal and non-verbal cues (e.g. body movement, posture, facial expressions, eye contact, etc.), communication is seen as a fluid process, which requires detailed understanding in game design [22].

However, while game studies have explored variations in the verbal communication patterns of young players in role-play and first-person shooter games [e.g. 8, 10], there is a paucity of research that has empirically investigated differences in communication among more diverse groups. Of the few examples, Derboven et al. [9] examined the exchange of verbal utterances in an intergenerational shopping game, while our earlier research explored the communication relationships between younger and older players [19]. Subsequently, to our knowledge there are no known game studies that have quantifiably compared communication

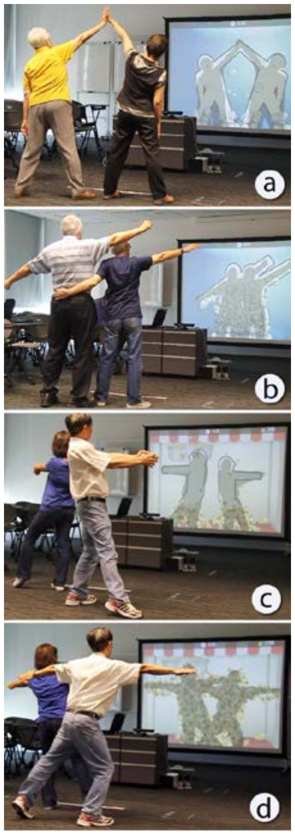

Figure 2. Wide base (**a-b**) and narrow base poses (**c-d**). When correctly positioned, animated objects fill up over the body templates. Participants are then required to hold positions until the templates are completely immersed.

behavior across two or more independent groups of older adults.

As a result, much of the inspiration for this study draws influence from a wider examination of dyadic interaction in social studies, where directive sequences are carefully deployed in goal-orientated tasks. In this context, the definition of a *directive* is taken from Bernicot and Legros's [2] description of an intentional act by a speaker to make a listener 'do something'. Insightful research using communication cues include the works of Camras [6] who explored the dyadic relationship of children in conflict situations; Cekaite's [7] descriptive reporting of embodied actions in the parental shepherding of young children; and LeCouteur and Feo's [14] examination of orchestrated actions among sports players.

Commonly, such works highlight the interchangeable relationships between subjects' bodily orientation, gaze, touch and conversational speech during strategic forms of interaction. As such, these findings have helped form a basis of interest in this study, in terms of understanding how similar types of behavior may be used in collocated gameplay.

Method

A two month study with 20 older participants who differed, among other aspects, in their education, technology literacy and physical functioning was undertaken to compare their dyadic communication. Specifically, the primary aim of the study was to identify possible differences in the verbal and non-verbal interaction of paired players, particularly in relation to more prolonged gameplay exposure.

Prototype game

A full-body gesture-based game was designed to encourage partner cooperation, while evoking a controlled form of physical exercise. A series of light to moderate steady-state poses were used to challenge player's balance control. These varied from wide and stable base positions (e.g. two footed) to a smaller base (e.g. single or dominant leg stances) with a greater amount of sway (Figure 1). Twenty-four balance positions were developed in the form of different on-screen body templates, in consultation with geriatric physiotherapists over a 5 month period. Unlike prior game studies that have focused on improving balance through sequential stepping actions [e.g. 16, 20], performance measures in this game were based on holding 'static' positions to stretch related muscle groups for body strengthening and flexibility.

The game setup consisted of a 2 meter projection screen, a short-throw projector and a laptop to run the software. For image processing, the Kinect's IR depth camera was used to detect the shapes of the players' bodies, and project them as a full-scale image. Players then directly interacted with a mirrored image in the form of a *graphical silhouette*, using a computer algorithm to track and calculate a matching percentage against the on-screen body templates (Figure 2).

Over 16 levels were designed in the game requiring players to appropriately fit their silhouette into separate body templates. To encourage cooperation, both players were allocated 5 seconds at the start of each level to review the positions of the body templates before the level automatically began. Once correctly aligned within these shapes, players were required to hold the correct position for about 40 seconds.

	I-L	C-S	*P* value
Pre-test			
Gait speed – *normal* (m/sec)	1.24 1.18 (.71)	.70 .63 (.88)	<.001
Single leg stance (secs)	20.02 24.30 (26.7)	6.65 3.85 (25.5)	<.01
Timed Up and Go (secs)	7.20 6.92 (3.3)	12.61 12.05 (11.8)	<.001
Post-test			
Gait speed – *normal* (m/sec)	1.27 1.28 (.35)	.68 .75 (.54)	<.001
Single leg stance (secs)	21.19 28.56 (24.9)	5.44 2.15 (21.3)	<.01
Timed Up and Go (secs)	7.48 7.23 (3.6)	13.06 10.62 (20.0)	<.001

Table 2. Results of the pre- and post-testing with mean (*top*), median and range values in parentheses. P-values represent *between* subject results.

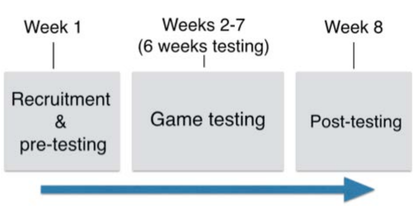

Figure 3. Overview of study.

Animated graphical objects would then fill up inside the body templates, and once full, signify the successful completion of a level. If one or more of the players were poorly positioned, the falling objects would stop or slow down until appropriately corrected. This was designed to encourage players to collaborate and intervene with assistance when necessary. A countdown time of 60 seconds was set in each level, and players were rewarded with accumulative points.

Participants

All the participants were aged 60 years old or above. They were recruited via volunteer center managers who were asked to identify potential participants based on health guidelines established by Grieg et al. [12]. For example, participants were excluded if they had heart or breathing problems, high blood pressure or acute arthritis, and had to be able to engage with the game without the support of a walking aid, or have no known cognitive impairments.

Once selected, participants were then separated into two groups we defined as *independent-living* (I-L) and *community-supported* (C-S). These groups differed in their *education*, *language*, *technology literacy* and *physical functioning*. Specifically, the C-S group consisted of participants from the same senior activity center. They had a low education and technology experience, and only spoke in Chinese dialects. These participants regularly attended the center for subsidized meals and financial support. Alternatively, the I-L participants were recruited from multiple ageing centers, and were proficient English speakers, with a greater amount of technology experience and higher education qualifications (Table 1).

Gait speed, single-leg stance and the *timed up and go test* [see 4, 5 and 17] were administered to measure the mobility of the participants. These are established measures that can be conducted in a non-clinical setting. For consistency, the same measurements were administered at the start and the end of the game testing to help indicate if the game *may* have had a mediating effect on player's physical performance (recognizing this is not a controlled physiological study).

As seen in Table 2, non-parametric Mann-Whitney U tests identified that the I-L group performed significantly better than the C-S group on all the physical measurements. In contrast, no significant differences were identified *within* groups ($p > .05$).

Group		**I-L**	**C-S**
Sample size		10	10
Age (mean±S.D.)		66.8±4.4	72.8±9.0
Sex (male/female)		4/6	1/9
Education:	*Degree*	10%	0%
	Diploma	10%	0%
	A-level	20%	0%
	O-level	50%	40%
	Below O-level	10%	60%
Technology Experience:	*Use of a mobile phone*	100%	10%
	Use of the Internet	100%	0%
	Play digital games	50%	0%

Table 1. Demographic details (grey highlights differences).

Procedure

For the I-L participants the game testing was conducted at the research institute, while the C-S participants were tested at the local senior center they regularly

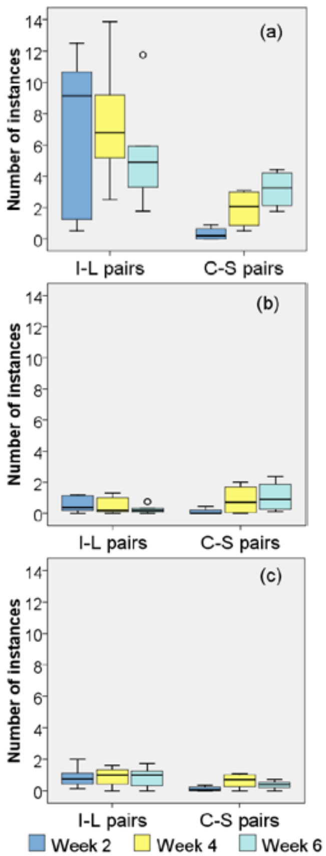

Figure 4. Medians and interquartile ranges of paired instances per game level for (**a**) verbal communication, (**b**) physical directives, and (**c**) non-verbal communication directives. Circles represent outliers.

attended (the travel distances between the two groups meant it was unfeasible to test at the same site). However, both sites had comparable seating arrangements, space and lighting.

A week prior to the start of the game testing, participants were assigned to a group of 4-6 people and pre-tested using the physical measurements previously described. As feasibly possible, pairs were matched on the premise that they did not personally know each other, and that they spoke the same language. Barring two separate instances, partners remained the same throughout the study, and no casual observers were present.

During the first week of the game testing, the briefing of the game consisted of a practice trial of the first three levels. For subsequent weeks, the gameplay lasted approximately 15-20 minutes per session, with a minimum gameplay time of about 10 minutes (or 8 levels). This process was repeated once a week, for six weeks. At the end of the sixth week, participants were group interviewed on their experiences of playing the game. The following week, a post-test was conducted using the same physical measurements as the pre-test (Figure 3). Throughout the study, three researchers were regularly on site to ensure the safety of participants, two of whom were fluent in both Mandarin and English.

Post-game measures & data analysis
To understand the intentional communication of players, observational measures were obtained through video analysis. Two independent coders analyzed all the video recordings, and interobserver reliability was checked based on an occurrence percentage agreement of over 85%. Each gameplay level was then coded using a series of behavioral measures that were classified based on our prior work on intergenerational gameplay [19] and the modification of informational gestures as reported by Boguslawski [3]. These were defined as:

- *Verbal communication*: includes all utterances and non-word vocalizations (e.g. laughter, gasps, etc.).
- *Physical directives*: includes physically pulling, tapping or steering a partner into position.
- *Non-verbal communication directives*: includes nodding, pointing or waving to a partner.

For each game level, a count of the number of behavioral occurrences was completed. For statistical analysis, given the sample size, non-parametric Mann-Whitney U tests (2-sided) were used to identify differences across conditions. Given variations in the number of game levels played, pair scores were summed and averaged for weeks 2, 4 and 6. Due to a loss of video data, the data set of one C-S pair was removed from the statistical analysis.

In support of the video data, descriptive field notes were analyzed to review instances of player behaviors. Similarly, audio recordings of the semi-structured group interviews (each approximately 30-40 minutes long) were reviewed to assess participant's interests and understanding of the interactive game. This data was manually coded for further analysis.

Communication findings
To highlight the variations between the groups, we provide a number of key insights based on players' communication behavior.

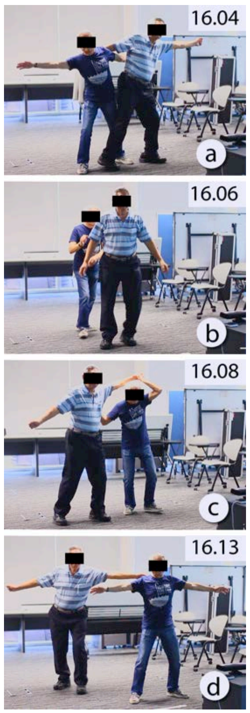

Figure 6. An example of the 'partner switching' demonstrated by an I-L pair. Player 1 (*left*) shakes his head, then says "Change. Change" (**a**). Player 1 steps back (**b**), then moves forward, under his partner's left arm, pulling on his hand to infer to keep that arm position (**c**). Player 2 then moves backward keeping his arms extended, while player 1 moves a few paces forward (**d**).

Verbal communication as a dynamic process

As illustrated in Figure 4a, in comparing the frequency of verbal utterances between the two groups, a stark difference was identified in the patterns of verbal communication over the duration of the study.

For example, for the I-L pairs, the number of utterances was reported highest in **week 2** (*Mdn* = 9.13), and lowest in **week 6** (*Mdn* = 4.90). In contrast, there were a negligible number of utterances in the C-S pairs in **week 2** (*Mdn* = .20) compared to a notable improvement in **week 6** (*Mdn* = 3.25). Statistical comparisons further revealed a significant higher number of utterances in the I-L pairs across **week 2** (U = 1, p < .05, r = -.74) with a considerable trend towards significance in **week 4** (U = 2, p = .06, r = -.65), but not in **week 6** (U = 5, p = .29, r = -.41).

To help account for these differences in interaction, a review of the average number of utterances in the first *15 seconds* of each level compared to the total, revealed a contrasting pattern of verbal communication for the two groups between **week 2** (I-L pairs: 45%, C-S pairs: 0%) and **week 6** (I-L pairs: 30%, C-S pairs: 28%).

Supported through the video observations, the early gameplay sessions identified that the I-L pairs were very 'proactive' in verbally assisting their partner's physical orientation at the beginning of a level, but intervened less as the dyads became more proficient in the game. In the early weeks, this included a high number of verbal directives, which were typically short and at times ambiguous (e.g. *"Leave it"*, *"Raise your hand again"*, *"Face me"*). In comparison, the negligible amount of verbal communication in the early sessions for the C-S pairs was reflective of more rigid and stationary positioning, requiring more repetitive practice of the game to gain better comprehension.

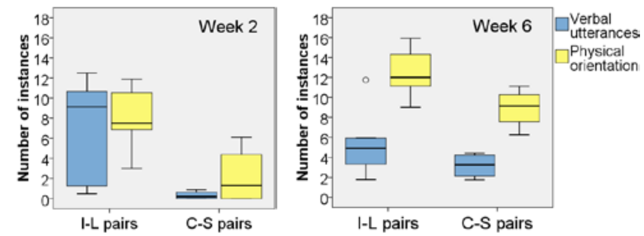

Figure 5. Comparison of verbal communication (as reported in Figure 4a) to physical orientation for weeks 2 and 6. Physical orientation was defined as the number of instances players directionally moved (by stepping) to re-adjust their position to screen.

For example, comparing the number of verbal utterances with physical movements revealed an interesting change of behavior (see figure 5). Namely, for the C-S pairs, we noted that progressive improvements in verbal interaction were accompanied with a greater amount of physical orientation. On the other hand, a reduction in verbal communication compared to an increase in directional movements for the I-L pairs, suggests that as they became more competent in playing the game, individual players were required to be less instructive.

As a result, for the I-L players, as confidence grew in their paired interaction, we observed an increasing number of times that players would switch positions to reverse roles, either to assist a partner, or plan ahead in the levels. As illustrated in Figure 6, this was often done with a minimal amount of verbal instructions, as players would re-orientate themselves while remaining

Figure 7. Gameplay examples of the physical and non-verbal communication directives.

directionally focused on the screen and game content. Mastering the shared physical space and proximity between themselves and their partner, interestingly, we noted no similar examples of positional switching by the C-S pairs.

Use of non-verbal and physical directives

As shown in Figure 4b-c, there were a low number of directives in the study, with only one significant difference identified in non-verbal communication in **week 2** (U = 1, p < .05, r = -.74; I-L: *Mdn* = .75, C-S *Mdn* = .06). Despite this, similar to trends in verbal communication, the results indicate that the C-S pairs increased their use of physical directives over the duration of the study (**week 2**: *Mdn* = .00, **week 6**: *Mdn* = .91), compared to a marginal decrease in the I-L pairs (**week 2**: *Mdn* = .38, **week 6**: *Mdn* = .20).

Further inspection of the directives identified that players from both groups would help to physically *stabilize* a partner's position (e.g. by stretching out an arm), and predominately used *pointing* and *waving* gestures as directional instructions (see Table 3). Alternatively, there were noticeable differences in the way the groups would tactilely guide the actions of others. Namely, we identified that the I-L pairs were more likely to *touch* or *tap* a partner to gain their compliance. This was notably different to the C-S pairs who were generally more physical in *steering* a partner into position by pushing or pulling on a body part (e.g. an arm or leg) to help realign their physical orientation (see Figure 7).

Commonly used in clusters, the touching gestures by the I-L pairs were often employed to gently reassure a partner at the start of a level, while the steering actions by the C-S pairs were bolder and more disruptive movements that often required a longer time to implement. In what Cekaite refers to as variations in the quality of touch [7], the subtle nature of the touching gestures appear to be an important attribute of the early team bonding process, which may help explain why they were used less frequently by the I-L players in the subsequent weeks (Figure 4b).

Averaging the combined number of physical and non-verbal directives within the pairs revealed that the scaffolding of these actions was more likely to be orchestrated by the *same* player (over 80% in both groups).

Physical directives	I-L	C-S	*Non-verbal com. directives*	I-L	C-S
Steer	29%	60%	**Point / wave**	99%	92%
Touch / tap	54%	26%	**Kick**	0%	8%
Stabilize	17%	14%	**Nod**	1%	0%

Table 3. Type and average percentage of physical and non-verbal communication directives per group (grey highlights differences).

Group perceptions of dyadic interaction

Subjective feedback identified that the I-L pairs were more likely to positively report on how the game encouraged coordination, communication and teamwork, and that a good rapport was needed to achieve what was described as 'focused interaction'. This included remarks that the repetitive nature of the game helped build trust and a 'good chemistry' between the players: *"You need to prompt your partner, that is why you will see us whispering, 'move here', 'move there'… so I think for both of us, I think we sort of progressed quite fast in that aspect*".

In contrast, the C-S participants were more critical of their performance, which they related to the attentional demands of understanding the game: *"We were too focused in trying to complete the actions of the game and so we did not engage in more verbal communication with our partner, as there was no time to both talk and imitate actions"*. As a result, fewer of the C-S participants openly acknowledged improvements in their social interaction, which were commonly undermined in conversations by their perceived weaknesses in playing the game.

Discussion

Overall, our results indicate that group differences are most noticeable during the early sessions, with the C-S players more inclined to play individually, and only improve their pro-social behavior through practice. Alternatively, the I-L pairs were quick to socially engage with their partner, leading to a greater mastery of the game, and reduction in communication, which we observed in the later weeks.

For both groups, there remained a high degree of player dominance, while the higher frequency of tapping and touching gestures by the I-L pairs indicated more subtle forms of partner coercion, compared to the steering actions, which can be seen as more implicit strategies of control [7]. On the other hand, the low number of directives compared to verbal utterances can be attributed to the 'style' of the game, and the disruptive nature of physically moving while holding a static position.

Notably, while there were some functional differences between the groups, all players were physically capable of playing the game. Naturally, some of the more dynamic poses were difficult to accomplish, but this was intentionally done to sustain engagement over the duration of the study.

Addressing the study limitations

Based on our current study, we recognize that further research is needed to validate the characteristics of these two groups. In particular, a more controlled investigation of the factors which warrant group differences, given variations in player age, education, language, technology literacy and physical functioning, and limitations in sample size and gender distribution. On the other hand, we believe these exploratory findings provide a good means for questioning the importance of understanding communication practices among more diverse user groups, particularly in relation to measuring gameplay effects over time.

For example, unlike HCI game studies that have reviewed interaction over a single session, our results suggest that taking a similar approach would have provided a skewed perspective on players' engagement, and failed to account for the changing communication patterns observed. Subsequently, we believe these findings emphasize a need for serious games studies to better consider the importance of measuring gameplay effects over a longer period of time. This reflects on the work of Drachen and Smith, who articulate a need to *"refrain from simplistic notions about how communication and player experience are connected*" [10, p.33].

On the other hand, despite finding no statistical differences in the physical functioning within groups, our research highlights that even within a small number of players, significant changes and trends in communication can be observed. This suggests that game evaluators should take advantage of using communication cues to help analyze player usage and interaction patterns.

Moreover, given the intertwining relationships between education, income, technology literacy and health among different socio-economic groups, we note that separating out these factors is a challenge for HCI game research. For example, it is well established that advantaged individuals are more likely to be better educated and have better computer access compared to those on low income [21].

Further opportunities of investigation
In terms of game design, although previous research has explored the notion of adapting game content to match the physical requirements of older adults [e.g. 11], to our knowledge there is a lack of understanding in how digital games should accommodate for variations in inter-player communication. Among low socio-economic groups, these include understanding the types of game 'triggers' or awareness cues that should be used to help facilitate coordination and early cognitive learning, and build group cohesion and trust.

In addition, beyond understanding the influence of game-type, social setting and partner familiarity in communication practices, game research can also extend to looking at other types of non-verbal behavior. For example, how personality traits may attribute to underlying differences in players' interaction, given socially avoidant individuals are considered to be less sensitive to the communication cues of other people [15].

Finally, given the focus on player diversity, there are unanswered questions towards how well communication practices translate to other heterogeneous groups of older adults, or segments of the population (e.g. for rehabilitation, cognitive assistance or intergenerational support). Given the South-east Asian focus of this study, this includes opportunities to understand the extent gameplay communication may be influenced by linguistic and cultural differences, which are less dominated by Western perspectives. These include not only examining differences on national levels, but also within local subcultures and ethnic groups.

Conclusion

In summary, we have demonstrated how communication practices can significantly differ between groups of older adults, and how directive behaviors can be used to understand these dyadic relationships. A very limited amount of work has empirically explored the communication practices in older adults and serious games. As a result, we believe that this research raises important questions in how embodied actions can help identify a deeper understanding of player's interactional engagement in diverse groups, particularly in terms of the types of intervention and social strategies used.

Acknowledgements

The authors would like to thank the support of Karin Ho, Melissa Zee Wei Lin, Xiangting Su, Vanessa Yeo, Valerie Tang Hui Wen, Cherine Quek, the staff at the Henderson Senior Activity Centre, the physiotherapists at Khoo Teck Puat Hospital, and all the volunteers. This research was funded by A*STAR SERC Human Factors Engineering TSRP Research Grant.

References

[1] Andrews, G. Gameplay, gender and socioeconomic status in two American high schools. *E-learning and Digital Media 5*, 2 (2008), 199-213.

[2] Bernicot, J., & Legros, S. Direct and indirect directives: what do young children understand? *Journal of Experimental Child Psychology 43*, 3 (1987), 346-358.

[3] Boguslawski, G. Body movement, social interaction and engagement in video game play: It's a different game all together. M.Sc. thesis, University College London, 2007.

[4] Bohannon, R.W., Larkin, P.A, Cook, A.C., Gear, J., & Singer, J. Decrease in timed balance test scores with aging. *Physical Therapy 64*, 7 (1984), 1067-1070.

[5] Bohannon, R.W. Comfortable and maximum walking speed of adults aged 20-79 years: reference values and determinants. *Age Ageing 26*, 1 (1997), 15-19.

[6] Camras, L.A. Children's verbal and nonverbal communication in a conflict situation. *Ethology and Sociobiology 5*, 4 (1984), 257-268.

[7] Cekaite, A. Shepherding the child: embodied directive sequences in parent-child interactions. *Text & Talk 30*, 1 (2010) 1-25.

[8] Cheung, V., Chang, B., & Scott, S.D. Communication channels and awareness cues in collocated collaborative time-critical gaming. In *Proc. CSCW '12*, ACM Press (2012), 569-578.

[9] Derboven, J., Van Gils, M., & De Grooff, D. Designing for collaboration: a study in intergenerational social game design. *Universal Access in the Information Society 11*, 1 (2012), 57-65.

[10] Drachen, A., & Smith J.H. Player talk -The functions of communication in multplayer role-playing games. *ACM Computers in Entertainment 6*, 4, Article 56 (2008).

[11] Gerling, K.M., Livingston, I.J., Nacke, L.E., & Mandryk, R.L. Full-body motion-based game interaction for older adults. In *Proc. CHI '12*, ACM Press (2012), 1873-1882.

[12] Greig, C.A., Young, A., Skelton, D.A., Pippet, E., Butler, F.M.M., & Mahmud, S.M. Exercise studies with elderly volunteers. *Age Ageing 23, 3* (1994), 185–189.

[13] IJsselsteijn, W., Nap, H.H., de Kort, Y., & Poels, K. Digital game design for elderly users. In *Proc. Future Play '07,* ACM Press (2007).

[14] LeCouteur, A., & Feo, R. Real-time communication during play: analysis of team-mates' talk and interaction. *Psychology of Sport and Exercise 12*, 2 (2011), 124-134.

[15] Patterson, M.L. Nonverbal communication. In V.S. Ramachandran (Ed.) *Encyclopedia of Human Behavior (*2nd Edition), Academic Press, London (2012), 731-738.

[16] Pichierri, G., Coppe, A., Lorenzetti, S., Murer, K., & de Bruin, E.D. The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: a randomized controlled pilot study. *Clinical Interventions in Aging 7* (2012), 175-184.

[17] Podsiadlo, D., & Richardson, S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society 39*, 2 (1991), 142-148.

[18] Rabbitt, P. Cognitive changes across the lifespan. In M.L. Johnson (Ed.), *The Cambridge Handbook of Age and Ageing*. Cambridge University Press, Cambridge (2005), 190-199.

[19] Rice, M., Tan, W.P., Ong, J., Yau, L.J., Wan, M., & Ng, J. The dynamics of younger and older adult's paired behavior when playing an interactive silhouette game. In *Proc. CHI '13*, ACM Press (2013), 1081-1090.

[20] Schoene, D., Lord, S.R., Delbaere, K., Severino, C., Davies, T.A. & Smith, S.T. A randomized controlled pilot study of home-based step training in older people using videogame technology. *PLoS ONE 8*, 3 (2013).

[21] Silver, M.P. Socio-economic status over the lifecourse and internet use in older adulthood. *Ageing and Society 34*, 6 (2014), 1019-1034.

[22] Toups, Z.O., Hammer, J., Hamilton, W.A., Jarrah, A., Graves, W., & Garretson, O. A framework for cooperative communication game mechanics from grounded theory. In. *Proc. CHI Play '14*, ACM Press (2014), 257-266.

[23] Woo, J., Chan, R., Leung, J., & Wong, M. Relative contributions of geographic, socioeconomic, and lifestyle factors to quality of life, frailty, and mortality in elderly. *PLoS ONE 5*, 1 (2010).