Gender and Generation Differences in the Acceptability of a Tangible Robot-like Neurofeedback Learning Companion: a Feasibility Study

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I did not use AI to produce content. I do acknowledge that ChatGPT (OpenAI, 2025) was used in this thesis to translate words from Dutch to English and to find synonyms of words. Lastly it was used to give assistance on word order improvement. Prompts that I used are for example: ‘Can you give a translation for “verhogen” to English?’, ‘Give me some synonyms for examine’, ‘Is this sentence grammatically correct?’, ‘What is a different word for aim?’, ‘What are good concluding linking words?’.

With the approval of our supervisor Stefanie Enriquez-Geppert, I have exceeded the 6000 words in this thesis.

Abstract

Introduction: Neurofeedback for certain parts of cognition has shown promising results to be effective in some studies, however, not all individuals benefit equally and a great learning variability between participants has been observed. To potentially improve outcomes for neurofeedback, innovative new technologies such as a tangible robot-like neurofeedback learning companion have been proposed. Previous research reveals differences between gender and generation in the acceptability of new technologies. This study investigates whether such a tangible robot-like neurofeedback learning companion for neurofeedback is accepted and whether this acceptability differs between gender and generations.

Methods: 613 participants completed the online questionnaire and entered the analysis. They were asked to share their demographics and different aspects about the learning companion and about acceptability, rating on a scale from 0 to 100. A Two-Way ANOVA was used to assess the research question, following up with a Gamer-Howell post-hoc test. Acceptability provided as the dependent and within-subject variable. The independent and between-subject variables were Gender (Men, Women) and Generations (Generation Z, Millennials, Generation X, Baby Boomers). A score of 60 out of 100 was set as the threshold for the intervention to be considered as 'accepted'.

Results: The overall score of acceptability showed that the tangible robot-like neurofeedback learning companion was accepted (M = 66.74, SD = 16.42). No significant difference was found between gender on acceptability of the tangible robot-like neurofeedback learning companion ($F(1, 605) = 0.15$, $p = .70$, partial $\eta^2 = .00$). A significant difference was found between Generation X and Generation Z ($F(3, 605) = 3.06$, $p = .03$, partial $\eta^2 = .02$), where Generation X (M = 71.99, SD = 2.04) showed significantly more acceptability than Generation Z (M = 65.67, SD = 0.71). No interaction between Gender and Generation was found ($F(3, 605) = 1.16$, $p = .33$, partial $\eta^2 = .01$).

Discussion and conclusions: Concluding, this research provides insights for future neurofeedback studies by demonstrating that the tangible robot-like neurofeedback learning companion is overall accepted by participants. However, further research is recommended to explore gender and generation differences on the acceptability, since this study did not include equal group sizes for these categories.

Keywords: Acceptability, Tangible Robot-like Neurofeedback Learning Companion, Neurofeedback, Gender, Generations

Gender and Generation Differences in the Acceptability of a Tangible Robot-like Neurofeedback Learning Companion: a Feasibility Study

While neurofeedback showed potential to be effective for enhancing certain aspects of cognition, like attention regulation, (e.g. Viviani & Vallesi, 2021; Enriquez-Geppert et al., 2014; Smit et al., 2023; Zoefel et al., 2011), these same studies also report people who do not respond to the neurofeedback training (also called "non-responders"). Approximately 16% to 57% of the individuals fail to achieve self-regulation during neurofeedback sessions (Alkoby et al., 2018). Furthermore, some individuals achieve results and improvements quickly, while others progress more slowly (Enriquez-Geppert et al., 2017). This suggests that there is a wide range in effectiveness between individuals. This highlights the need to improve neurofeedback. For example, Oblak et al. (2019) aimed to improve neurofeedback by optimizing which time point of the brain signal to use, which brain region to target and how much data is needed to ensure reliable neurofeedback. Another potential way to increase the efficacy of neurofeedback, and potentially reducing the number of non-responders in future clinical neurofeedback trials, is the use of a robot-like neurofeedback learning companion to provide real-time assistance during neurofeedback.

Neurofeedback to Enhance Executive Functions

Neurofeedback is a form of biofeedback in neurocognitive training, that has a brain-computer interaction which helps individuals to train and regulate their brain activity (e.g. Viviani & Vallesi, 2021; Batail et al., 2019; Kadosh & Staunton, 2018; Weiskopf, 2012). Due to real-time feedback, which helps to recognize patterns of activity in the brain, an individual learns how to alter patterns of this activity (Alkoby et al., 2018). It addresses underlying core brain functions that are involved in cognition (Smit et al., 2023) and this particular form of neurofeedback is based on a learning principle (Enriquez-Geppert et al., 2017). Operant conditioning, an example of a learning principle in neurofeedback, assumes that the likelihood of a behaviour increases when it is followed by positive reinforcement, and decreases by negative consequences (Enriquez-Geppert et al., 2017).

Executive functions are cognitive processes that neurofeedback aims to improve. They are part of cognition, which focuses on the mental processes that affect behavior (e.g. thinking, learning) and are crucial in an individual's daily functioning (Savarimuthu & Ponniah, 2024; Esmaili et al., 2023). Executive functions are higher levels of cognitive processes that help people to control their mental processes and actions when achieving goals (Friedman & Miyake, 2017). Miyake et al. (2000) considered set-shifting (switching between mental tasks), working memory updating (tracking and interpreting task-relevant information, removing old information and adding useful information) and response inhibition (suppressing automatic responses) as important executive functions. Enriquez-Geppert et al. (2010) added conflict monitoring (identifying conflicts in information processing, leading to a change in strategies) as a component of the executive functions.

Neurofeedback protocols targeting the frontal-midline theta activity (4-8 Hz firing rate per second), recorded by an electroencephalography (EEG), were shown to effectively improve executive functions (Smit et al., 2023; Viviani & Vallesi, 2021). As neurofeedback has the potential to improve executive functions, individual success can still vary (e.g. Viviani & Vallesi, 2021; Enriquez-Geppert et al., 2014). Integrating a tangible robot-like neurofeedback companion may potentially enhance neurofeedback effectiveness.

Tangible Robot-like Neurofeedback Learning Companion as a New Technology

Chou et al. (2003) characterized a learning companion as a non-authoritative, computer-based educational intelligent tutoring system that promotes learning by interacting with individuals and helping them with personalized assistance. A tangible robot-like neurofeedback learning companion is a newly developed subcategory of a learning companion. It will be considered as a new technology, as it is newly formed and therefore it remains largely unexplored, with limited research that has been done. It can help participants to stay motivated and interpret feedback more easily (Pilette et al., 2020). Additionally, they can create positive emotions, like confidence, that support learning, while reflecting emotional states (Arroyo et al., 2009). It gives complimentary feedback in comparison to normative data of the participant, while always being positive and constructional. In the field of neurofeedback, Pillette et al. (2020) introduced a tangible learning companion for Mental-Imagery Brain-Computer Interface (MI-BCI) training for the first time. MI-BCI training uses brain-activity (recorded by EEG) as well, the tangible neurofeedback companion was added to provide social presence and emotional support in a non-authoritative way during the sessions, which are crucial to improve the learning (Johnson & Johnson, 2009; Pilette et al., 2020). Their study shows that incorporating a learning companion can be beneficial in MI-BCI training. Improvements were shown in learning and memorability and usability of MI-BCI (Pilette et al., 2020). So these findings suggest that integrating tangible robot-like learning companions in neurofeedback, although the protocols differ between neurofeedback and MI-BCI, can result in improvements for learning outcomes of neurofeedback.

Following, studies showed that the use of an virtual, digital, interactional learning companion which communicates, can increase cognitive abilities, including problem solving, critical-thinking and self-regulation, by providing guidance, motivation and emotional support during learning tasks in areas like critical thinking and mathematics (Aprin et al., 2024; Woolf et al., 2010), which are also related to cognition. In these studies, the companions monitored the learning, offered empathy and guided the participants through the learning process of these tasks. As a result, it was found that interactional learning companions improved affective outcomes, like anxiety (Woolf et al., 2010). Furthermore, in Lester et al. (1997), participants engaged with an animated pedagogical companion that could communicate and responded to problem-solving contexts in an interactive learning setting. Participants made a pre-test (problem-solving skills), then interacted with the animated pedagogical companion in a training module (assisting and providing advice, while students led their own learning process), following up with a post-test. It was found that in the interactive learning setting, the animated pedagogical companion could improve learning of problem-solving skills by offering personalized guidance during problem-solving and maintaining motivation (Lester et al., 1997). These findings relate to neurofeedback, as it also involves a learning process, where participants adjust their brain activity.

Importance of Feasibility in the Acceptance of the Tangible Robot-like Neurofeedback Learning Companion

However, all new treatments, especially those involving new technologies, should first be examined to see if they are accepted by the potential users, identify potential research obstacles, and be evaluated to increase the likelihood of implementation (Hagen et al., 2011). It is important to establish the feasibility of the study to determine whether a study can be implemented or if a treatment can be developed and applied in clinical settings (Orsmond & Cohn, 2015; Bowen et al., 2009). This is where the concept of a 'feasibility study' becomes important, which plays a central role in this process of development. A feasibility study is used to examine if a new treatment is useable for future research (Bowen et al., 2009), which can focus on different areas, like implementation, integration or acceptability.

Focussing on acceptability, Bowen et al. (2009) state that acceptability examines how both the individuals using the intervention and those responsible for implementing it, respond to the learning companion, following that Alexandre et al. (2018) states that acceptability can predict an individual's intention to use. They define acceptability based on utility, aesthetics (visually appealing) and ease of use (Alexandre et al., 2018), where ease of use specifically comes from Grevet et al. (2023) in the Acceptability Model for BCIs. There are three components of acceptability in this model: behavioural intention (BI), perceived ease of use

(PEOU) and perceived usefulness (PU). BI describes to the user's likelihood to engage with the intervention. PEOU describes if people believe they can use the system with minimal effort. PU refers to the beliefs of how beneficial a new system is (Grevet et al., 2023). These three components are necessary in treatment development and evaluation. Finding out if the intervention is easy to use, helpful, and engaging, helps to see if the treatment will be successfully implemented in clinical practice (Grevet et al., 2023). Understanding the acceptability of the tangible neurofeedback companion may lead to increased engagement, which might be critical for the improvement of neurofeedback.

The Role of Generations and Gender Differences on Acceptability of Technology

However, it is important to consider that acceptability may vary across different generations. While many studies focused on a certain age (e.g. Vroman et al., 2014, focussing on age 65 and above towards technology), examining differences between defined generations can offer more insights into people engaging with technology. For example, in Cecconi et al. (2025) they make use of the levels of generations (in interaction with new technologies): the Silent Generation (born in 1925–1945); Baby Boomers (born in 1946–1964); Gen X (born in 1965–1979); Gen Y (also: ‘Millennials'; born in 1980–1994); Gen Z (born in 1995–2009); and Generation Alpha (born in 2010–2024). In their research, they found differences in comfortableness with digital technologies (artificial intelligence, wearable technologies, and online health apps) between the different generations; where the Silent Generation shows the lowest level of comfort with technology and find it complex, compared to the other generations. The older generations had more difficulty with new technologies, compared to the younger generations (Cecconi et al., 2025). Other research showed that differences in early technology exposure contribute to how new technologies are approached, where the Silent Generation and Baby Boomers had less exposure and were less comfortable with technologies (Cekada, 2012). Generation X grew up while new technologies were upcoming, and were more comfortable than the older generations. Millennials viewed technology as important and expected it while learning (Cekada, 2012). Additionally, Gallagher et al. (2024) found that millennials approached technology differently (more use of technology) compared to older generations. It is interesting to investigate whether generation differences influence acceptability of technology, while also considering the potential effects of another variable, like gender.

Bao et al. (2014) conducted a study to find explanations for contradictory results on gender's moderating effect on technologies (e.g. e-learning), where they investigated gender differences in the implementation of these technologies. They found significant differences in acceptability of technologies between men and women, specifically in perceived ease of use and behavioural intention to use. Men thought these technologies were easier to use than women did and men showed a higher intention to use technology (Bao et al., 2014). They did not find any differences for gender in perceived usefulness. Burleson and Picard (2007) conducted a study to examine if an emotionally intelligent learning companion helps for motivation and lowering frustration during a problem solving activity. They did not find a significant result of the learning companion, however, they found that gender preferences explain the non-significance. They found that different genders (11-13 years old) showed differences between preferences in feedback from an emotionally intelligent learning companion (Burleson & Picard, 2007). Genders needed different feedback approaches, where boys preferred practical, task-focused guidance and girls preferred more emotionally aware companions (Burleson & Picard, 2007), which shows the importance of adapting support strategies of the learning companion. Additionally, a study was conducted to manage own health better, where the focus was on gender differences for the intention to use a new technology (mHealth) before implementation of it (Van Elburg et al., 2022). Significant differences between men and women were found for the intention to use this technology in medical applications, where men showed more intention to use the technology (Van Elburg et al., 2022). Moreover, Goswami and Dutta (2016) showed in a review that gender is an important variable to explain technology acceptance, where gender can play a role in acceptance of a new technology, however it is important to keep in mind that it depends on the context (Goswami & Dutta, 2016). Although these studies give insights about acceptability and technology, it remains unclear if there are gender and generation differences that have an influence on the acceptability of tangible robot-like neurofeedback companions.

Research Question and Hypothesis

Taken together, neurofeedback has been shown to be effective for certain parts of cognition, but some participants are not benefiting. This research aims to explore whether a tangible robot-like neurofeedback learning companion will be accepted to potentially increase the efficacy of neurofeedback for all users. There will be examined if gender and generations play a role in differences in acceptability of the robot-like learning companion, so these possible differences can be taken into account in future research to improve the learning for everyone. Based on previous literature, it is expected that for gender, men will show more acceptance toward the tangible robot-like neurofeedback learning companion and that younger generations exhibit higher levels of acceptability in comparison to older generations. Therefore, the research question that will be examined is: "Are there gender differences across different generations in the acceptance of a tangible robot-like neurofeedback learning companion for neurofeedback?".

To address this research question, the following hypothesis will be tested:

Hypothesis$_1$ (H$_1$): It is expected that there are a statistically significant generation differences for the acceptance (measured with the composite score of the questionnaire) of the tangible robot-like neurofeedback learning companion, where older generations will show less acceptability (than younger generations) (e.g. Cecconi et al., 2025). Furthermore, statistically significant gender differences are expected in acceptability of the tangible robot-like neurofeedback learning companion, where men will show more acceptability (than women) (e.g. Bao et al., 2014). Finally, a statistically significant interaction between generation and gender on acceptability is expected, where men of younger generations will show more acceptability than men of older generations.

Hypothesis$_1$ (H_0): There are no statistically significant differences for gender and generation on acceptability. Furthermore, there will not be a statistically significant interaction between generation and gender on acceptability.

Methods

Recruitment and inclusion criteria

The recruitment of the participants has been done through the network of bachelor students and the TULIP research team, the use of flyers and social media, and through writing emails to professionals who work in a psychological context. The minimum age for participating was eighteen years old and understanding one of the following languages was crucial: Dutch, English, Spanish, German, or French, as the questionnaire was available in these languages. The collection of the data started in February, 2024 and ended in April, 2025. The study questionnaire (PSY-2324-S-0092 *TULIP-acceptability study*) was approved by the Ethical Committee of the Behavioural and Social Science Faculty of the University of Groningen, Netherlands, and conducted in accordance with the Declaration of Helsinki.

Participants

This study used a convenience sample. There were *854* adult participants collected from different countries. The mean age was 29.03 years (*SD* = 15.04). The gender distribution is: 65.81% of the participants were women (n = 562), 20.26% were men (n = 173), 2.93% fell in the category “other” (n = 25) (this includes agender, androgyne, demigender, genderqueer, gender fluid, questioning, unsure, and 'another gender category'), and there were 11.01% of people who did not fill in anything regarding gender (n = 94). Participants were provided with information about their involvement before taking part in the study, as well as a description of how their data will be used following the ethical principles that protect the rights and well-being of participants. They gave informed consent to participate.

Procedure and materials

The questionnaire was created and distributed using Qualtrics. The participants completed the questionnaire on their own devices. The estimated duration required to complete the questionnaire was approximately thirty minutes. They had to sign the informed consent form in order to start the questionnaire. The questionnaire contained questions about demographics, cognitive problems, neurofeedback understanding and attitudes, the neurofeedback companion trustworthiness and acceptability, and personality traits.

Demographics Questionnaire

In the first part of the survey, questions related to sociodemographic background (age, gender, work status, completed education, residency, nationality, medical or health-related profession, history of psychiatric or neurological conditions) were administered.

Questions Regarding Experienced Cognitive Problems

Cognitive problems were measured using 14 items in which participants rated their response on a 3-point scale: *Yes, strongly*, *Yes, slightly*, or *No*. Multiple facets of cognitive problems were assessed, with each item introduced by a specific cognitive domain label, followed by a descriptive statement. The last item provided participants with the opportunity to report cognitive concerns not previously covered. An additional question was addressed regarding engagement in cognitive abilities training, in which participants rated their response on a scale from 1 to 100, with 1 indicating *Not at all* and 100 indicating *Yes a lot*.

Neurofeedback Educational Information

Participants received some information on neurofeedback. This also included some images that further explained this process. Participants also received some basic information on the goals of the neurofeedback companion. They were also shown a short video of the setup of neurofeedback, including the learning companion. Participants did a short quiz to show understanding of neurofeedback and the neurofeedback companion. After the quiz, participants had to answer a few questions on whether they felt like they understood what neurofeedback and the learning companion are.

Experiencing, Attitudes and Expectations regarding Neurofeedback & Related Techniques

Participants were asked about whether they had heard about neurofeedback before participating in this study, and if they had any previous experience with it. Finally, they were asked questions on a 0-100 scale on their attitudes and expectations regarding neurofeedback, with 0 being *completely disagree*, and 100 being *completely agree*.

Questionnaire Assessing the Design Preferences of the Neurofeedback Learning Companion

Participants were asked to indicate whether they had ever been in contact with a learning companion before, and if so, what kind of companion it was.

They were asked to rank four different companions based on the trustworthiness of their shape based on pictures included in the questionnaire. Moreover, participants were asked to indicate how trustworthy they found four possible names of the companion. Trustworthiness was indicated on a scale from 0 (*not trustworthy*) to 100 (*maximally trustworthy*). With trustworthiness we mean that participants would accept the learning companion's feedback and apply it during the neurofeedback sessions.

The type of color and the number of colors a trustworthy companion should have were evaluated as well. Participants were able to choose between four different options each.

Additionally, participants were asked to assess four voice samples and indicate which voice a trustworthy companion should have. The perceived fit of the voice was indicated on a scale from 0 (*not fitting at all*) to 100 (*maximally fitting*).

The behavior of the companion was evaluated as well. Participants were asked when they would like to receive feedback from the companion during the neurofeedback sessions (e.g. only when they succeed, only when they fail, or both) and whether they thought that a companion could distract them from neurofeedback. This last point was assessed using a scale from 0 (*completely disagree*) to 100 (*completely agree*).

Acceptability of Neurofeedback Companion Questionnaire

Acceptability was measured using eleven selected and adapted questions from the Acceptability Model for BCIs designed by Grevet et al. (2023). Within this variable, three key components were assessed using three questions for each: perceived ease of use, perceived usefulness, and behavioral intention.

In addition to the core domains of acceptability, the questionnaire also included one item each for both technology-related pleasure and confidence in using new technologies, suggesting the importance of psychological factors in acceptability (Grevet et al., 2023). All eleven selected questions were in the form of a visual analogue scale ranging from 0 (*totally disagree*) to 100 (*totally agree*).

Grevet et al. 's (2023) Acceptability Model has great internal consistency as demonstrated by the Cronbach's α scores ranging from .83 to .97 for the subdomains of acceptability. Regarding attitudes on technology, while the domain of pleasure shows a high level of internal consistency (α = .83), confidence in using new technologies is rated more poorly (α = .57).

Big Five Inventory

Personality was assessed using the Big Five Inventory (John et al., 1991), which consists of 44 items rated on a 5-point Likert scale ranging from *Disagree strongly* to *Agree strongly*. The questionnaire measures five personality domains, namely openness to experience, conscientiousness, agreeableness, extraversion, and neuroticism. The instrument demonstrates a good internal consistency, with Cronbach's α values ranging from .79 (Agreeableness) to .88 (Extraversion), and an average α of .83 across all domains (John & Srivastava, 1999). The personality scores were created by adding up the scores on the questions for each trait.

Statistical analysis

A Two-Way ANOVA was conducted to assess the hypothesis. The dependent variable was the composite score of Acceptability, which was the within-subject variable. Gender (Men, Women) and Generations (Generation Z, Millennials, Generation X, Baby Boomers) were the independent variables, which provided as the between-subject variables in the Two-Way ANOVA. Results of the main effect of Gender on Acceptability, the main effect of Generation on Acceptability and the interaction of Gender-Generation on Acceptability were found to test the hypothesis. If there were statistically significant results in the ANOVA, there were post-hoc tests performed to check between which groups the significant differences were.

To check the normality assumption of the Two-Way ANOVA analysis, the Shapiro-Wilk Test was used in combination with Q-Q plots. To examine the homoscedasticity assumption, Levene's test was used. In case of no violation of assumptions, the Bonferroni post-hoc test was performed. If there were violations of normality or homoscedasticity, a Gamer-Howell post-hoc test was used.

Although a priori power analysis was not performed, the final sample size (*N* = 613) is considered sufficient according to Faul et al. (2007). With our sample size being large, it seems to be powered to detect expected effects.

To assess acceptability, a score of 60 out of 100 was set as the threshold considering the intervention as "accepted". Therefore, if a participant rated above 60, the robot-like neurofeedback learning companion was viewed as accepted and perceived as positive, and can be used in further research. Where 50 is medium, we wanted to assess acceptability as more than the medium. Under the assumption that a score of 60 reflected a higher level of acceptability, this threshold was selected.

The statistical analyses that were done in this research, were performed with the use of IBM SPSS Statistics v.19 (2023).

Results

Assumptions

A Two-Way ANOVA was conducted to test the hypothesis. Prior to the analysis, the assumptions were assessed. The Shapiro-Wilk tests showed a violation of the normality assumption ($p < .001$), where the Q-Q plots mostly confirmed a violation, except for Baby Boomers ($p = .247$). Moreover, Levene's Test showed a violation of homogeneity of variances ($p = 0.035$), due to a large sample size, ANOVA remains reliable under heterogeneity (Maxwell & Delaney, 2004).

Descriptives of Gender, Generation and Acceptability

Table 1 shows the basic descriptives of gender and generation. The initial sample contained 854 participants. A total of 214 participants were excluded from the final analysis for the following reasons: participants who identified themselves as 'Other' ($n = 25$), belonged to the 'Silent Generation' ($n = 4$), who did not want to share their age ($n = 12$) or did not complete the questionnaire up to the 'Acceptability' part ($n = 219$). The final sample included 613 participants. Additionally, Table 1 shows the mean of the overall acceptability of

Table 1

Descriptives

		Full Sample (n = 854)	Final Sample (n = 613)
Gender, n (%)[a]			
	Men	170 (19.91)	142 (23.16)
	Women	563 (65.93)	471 (76.83)
	Other[b]	25 (2.81)	
Generation, n (%)[a]			
	Generation Z	546 (63.93)	481 (78.46)
	Millennials	71 (8.31)	43 (7.01)
	Generation X	104 (12.18)	67 (10.92)
	Baby Boomers	30 (3.51)	22 (3.58)
	Silent Generation	4 (0.47)	
Acceptability[c], M (SD)[d]			
	Overall	66.63 (16.48)	66.74 (16.42)
	Men	68.01 (1.32)	67.89 (1.32)
	Women	66.35 (0.77)	66.39 (0.77)
	Other[a]	62.46 (4.66)	
	Generation Z	65.65 (0.70)	65.67 (0.71)
	Millennials	66.05 (3.36)	67.16 (3.33)
	Generation X	72.03 (2.01)	71.99 (2.04)
	Baby Boomers	73.39 (3.68)	73.39 (3.68)
	Silent Generation	65.73 (12.05)	

Note. [a] The results show the number of participants, with the percentage of the total sample of that column shown in the brackets. [b] Other = Agender, Androgyne, Genderqueer or Genderfluid, Nonbinary, Questioning or Unsure, Prefer not to Disclose. [c] Acceptability was rated on a scale of 0 to 100. [d] The results show the mean, with the standard deviation shown in the brackets.

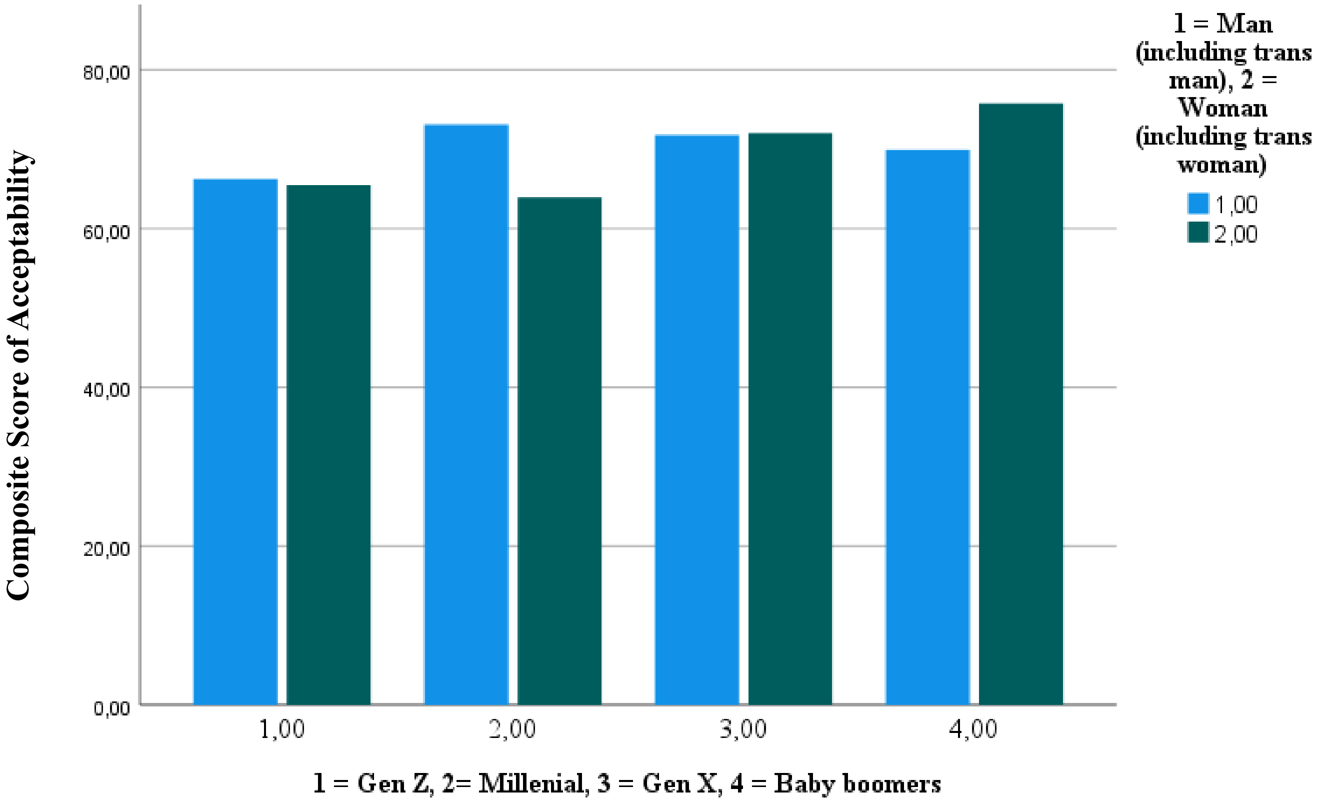
the final sample (M = 66.74, SD = 16.42), which indicates that all groups reported high acceptability rates. Generation Z showed the lowest acceptability rates (M = 65.67, SD = 0.71) , but still above the selected threshold (60) to interpret the tangible robot-like learning companion as ‘accepted’.

Main analysis of H1: Assessing the Effects of Generation and Gender on Acceptability

Figure 1 demonstrates a plot of mean scores of acceptability with gender per generation, which gives a view of how the scores are divided. There was no significant

Figure 1

Bar plot of Composite Score of Acceptability for Gender per Generation



difference found between men and women on acceptability of a robot-like neurofeedback learning companion, with $F(1, 605) = 0.15$, $p = .70$, partial $\eta^2 = .00$. The main effect of Generation was found statistically significant, $F(3, 605) = 3.06$, $p = .03$, partial $\eta^2 = .02$.

To examine the main effect of Generation, a post-hoc test was used with Games-Howell correction. The Games-Howell was chosen for the reason that this test does not assume equal variances and it is suitable when group sizes are unequal (Agbangba et al., 2024). There was a statistically significant difference in the acceptability of the neurofeedback learning companion, with Generation X (M = 71.99, SD = 2.04) rating it higher than Generation Z (M = 65.67, SD = 0.71), $p = 0.02$. The other mean differences between generations were not statistically significant.

The interaction effect between Generations and Gender was not statistically significant, $F(3, 605) = 1.16$, $p = .33$, partial $\eta^2 = .01$.

In summary, these results showed that the main effect of Generation is statistically significant, with a significantly higher acceptability for Generation X, in comparison to Generation Z. There was no main effect found for Gender, and no evidence for a gender-by-generation interaction. Therefore, the hypothesis was not supported.

Discussion

In the current feasibility questionnaire study, data of 613 participants were analysed to investigate if there are gender differences across different generations in the acceptance of a tangible robot-like neurofeedback learning companion for neurofeedback. It is important to examine acceptability as we need to know whether the tangible neurofeedback companion will be accepted and used in clinical practice by potential users and increase the likelihood of potential implementation. Our results show an overall acceptability score of the tangible robot-like neurofeedback learning companion that is high enough to find it ‘accepted’, which is above our threshold of 60. Our findings showed no effect of gender on acceptability, however an effect of generation on acceptability, specifically Generation X showing more acceptance than Generation Z was found. No interaction effect between Gender and Generation was found. We will look for explanations for the results compared to previous research, limitations and strengths of the study, implications and suggestions for future research.

Contrary to our expectations, the gender on acceptability of the tangible robot-like neurofeedback companion result was not observed. This finding is different from previous studies that found gender differences in the acceptability of new technologies, such as mobile learning environments (Bao et al., 2014), emotional intelligent learning companions to support during problem solving (Burleson & Picard, 2007), and the use of mHealth (an app in healthcare) in medical applications (Van Elburg et al., 2022). However, these studies also focused on different types of technologies and contexts, like education (Burleson & Picard, 2007) or adoption of mobile learning (Bao et al., 2014). How participants used the technologies also differed compared to our study. Importantly, these studies were more screen-based (not tangible), whereas our study focussed specifically on acceptability of a tangible robot-like neurofeedback learning companion for improvements of neurofeedback, which is unique and may explain the absence of an effect of gender. It is possible that the physical presence of the tangible robot-like neurofeedback companion reduced the gender differences in perceptions of acceptability. It suggests that gender effects on acceptability may be context dependent, where it can vary between technologies and application domains, and in some contexts might even disappear.

In contrast to the result regarding gender on acceptability, our findings showed differences for different generations on acceptability of the tangible robot-like neurofeedback learning companion, specifically that Generation X shows more acceptability than Generation Z. This result is not in line with our expectations and other literature which indicate that younger generations accept new technologies more than older generations (Cecconi et al., 2025; Cekada, 2012, Gallagher et al., 2024). However, these studies focused on different contexts and technologies like artificial intelligence and mobile health apps (Cecconi et al., 2025), which may explain the discrepancy with our findings, given the differences in the studies, domains and usage contexts. Additionally, it is possible that expectations toward technology have an influence on generational differences. Calvo-Porral and Pesqueira-Sanchez (2020) found that Millennials use technologies for entertainment purposes and Generation X uses it more for information seeking. In our study, it might be that Generation X perceived the tangible neurofeedback companion more like a useful and informative tool, which might explain their higher level of acceptability. Moreover, generational acceptability towards technology contains more factors like relevance and context of use. For example, Reich-Stiebert and Eyssel (2015) measured attitudes towards education robots in learning situations using an online questionnaire. Participants had to rate their attitudes toward educational robots on a Likert scale. They also found unexpected results, where older participants reported less negative views towards educational robots. A plausible explanation they proposed for their surprising results, was that older participants may perceived a lower personal likelihood of having to interact with this type of technology in their daily lives, as it can be less relevant in their lives. This could lead to more positive towards the educational robots as they do not have to directly interact with the robots (Reich-Stiebert & Eyssel, 2015). So this could apply in the current research as well, where Generation X may have less expectation to interact with the tangible robot-like neurofeedback companion. It suggests that generational differences in acceptability are formed by expectations.

Additionally, it was expected that differences in generation on the acceptability would be influenced by gender, so the effect of generation on acceptability would depend on whether participants identified as man or woman. However, this effect was not found, which did not correspond with our expectations. The absence of this effect might be explained by differences between previous research and the current study. Differences in technology, like the use of mobile learning environments (e.g. Bao et al., 2014) and differences in context when using a learning companion, for example to motivate during problem solving (Burleson & Picard, 2007), might explain why no combined effect was found. Participants might have all individual preferences and contexts (e.g. Reich-Stiebert & Eyssel, 2015), where gender and generation do not influence each other on the acceptability.

For future studies examining gender and generation differences within the context of technology, it is recommended to investigate if the overall use of new technologies increases. This can be interesting to know, since it might be related to the acceptability of new technologies. It might help to understand whether the absence of differences for genders and generations in acceptability could be influenced by a broader phenomenon.

Strengths and Limitations

One of the key strengths of this study is the large international sample size. This contributed to the ecological validity and the statistical power of the study. Additionally, there was a wide range of age, which showed that different ages were included in the research and the sample was diverse, enabling to explore the generational differences in a more representative way. Another strength is that this research used a newly developed technology. This adds originality and relevance to research, and also provides new insights into how this intervention is perceived by different groups.

An important limitation of this research is that the group sizes of generations and gender were not equally distributed. Unequal group sizes can increase the likelihood of violation of the assumption homoscedasticity (Parra-Frutos, 2012) and might contribute to skewing the distribution, which potentially has an effect on the interpretation of our findings. We found two violated assumptions: normality of residuals and homogeneity of variance, which might be due to the unequal group sizes. The results need to be interpreted carefully, as the reliability and validity of the research might be affected, which can affect Type I and Type II errors (Zhou et al., 2023), and the violations of these assumptions can lead to biased estimates. As a result, the findings of this paper should be interpreted while keeping in mind the violation of these assumptions. This underscores the importance to have equal group sizes.

Following up on this, our research used convenience sampling. This might have an influence on generalizability of the findings.

Following, our research did not assess individual thresholds for acceptability. In a review by Nadal et al. (2020), it is found that the usage of acceptability is not consistent in literature and studies failing to adapt their interpretation of it to their population. They suggest using acceptability consistently and adapting the measurement of acceptability to the particular context. Following on this, it remains unclear what a participant considers as ‘accepted’. As a result, it is hard to determine if their responses on the questions reflect acceptance or not.

Furthermore, it is reasonable to assume that participants were not completely focused anymore at the end of the questionnaire, taken into account that the ‘acceptability’ part was asked in the end and might not be completely reliable.

Implications and Future Research

The findings of the current research contribute to the growing field of neurofeedback research in several ways. First, it offers new insights into the acceptability of a tangible robot-like neurofeedback learning companion, which has not been researched before as an intervention to improve neurofeedback. This research gives more insight if a tangible robot-like neurofeedback companion is accepted and if future studies should invest in it. Understanding how different generations and genders see towards these neurofeedback companions, can give insight for further research to consider what kind of differences there might be, and ensuring that they can improve neurofeedback for all users.

Secondly, the result of Generation X showing more acceptance than Generation z, challenges the expectation that younger generations might be more likely to accept new technologies than older generations (e.g. Cecconi et al., 2025), which could be useful to take into account for development of this new intervention. No gender differences for acceptability of the tangible neurofeedback companion could be shown, which gives new insights about gender differences in acceptability of new technologies and can be interesting for future research about tangible robot-like neurofeedback learning companions.

Following, the practical relevance of this research is important, since practitioners in the (neuro)clinical field can use this research to improve neurofeedback interventions. This research brings insights prior to the development of the new intervention and contributes to the improvement of neurofeedback, which is necessary due to non-responders (Viviani & Vallesi, 2021), potentially increasing the efficacy of neurofeedback for everyone. It can be informational for clinicians, developers and researchers who are (potentially) users of neurofeedback for different purposes (Enriquez-Geppert et al., 2017). Overall, by exploring whether a tangible neurofeedback learning companion is accepted by potential users, these results provide a meaningful contribution for future research and early stage treatment development for potential improvement of neurofeedback and it helps to determine if further investment in these companions is valued.

For future research it is recommended that there will be a better focus on obtaining the same sample sizes in different age groups and genders. Moreover, it is suggested to first explore what participants define as ‘accepted’. In Terluin et al. (2023), they used an Item Response Theory based method to establish interpretive thresholds for patient reported outcome measures. Participants were asked if their level of pain was acceptable, and let them rate their pain on a scale, letting the researchers identify a score that was perceived as accepted. Building on this approach of Terluin et al. (2023), we propose for further research to ask participants to rate acceptability on a scale from 0 to 100 and make them pick a score that they consider as ‘accepted’. The mean score of all individual ratings on that question could then be used as the threshold score to work with for acceptability. This could help to determine more meaningful threshold scores. Lastly, it is recommended to include a check question between sections of the questionnaire to make sure participants remain focused.

Conclusion

Our findings indicate that no differences between men and women in the acceptability of a robot-like neurofeedback learning companion could be shown. There is a difference between generations, where Generation X scores higher on acceptability of our learning companion than Generation Z. However, no interaction effect was found between gender-and-generation. The overall acceptability score of the robot-like neurofeedback learning companion suggests that there is a higher likelihood of acceptance of the companion if individuals would participate in neurofeedback. A next step could be to integrate the tangible robot-like neurofeedback companion into neurofeedback and look at the acceptability when individuals participate. Concluding, this research gives more insight to the acceptability of such a learning companion for neurofeedback. Future research is needed to assess gender and generation differences on the acceptability, with more equally divided group sizes.

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Appendix A – Assumptions

Table A1

Normality of Gender on Acceptability

		Shapiro-Wilk		
	Gender	Statistic	df	Sig.
Acceptability	Men	.973	142	.006*
	Women	.976	471	< .001**

*p < .05. **p < .001.

Figure A1

Q-Q plot of Acceptability for Men

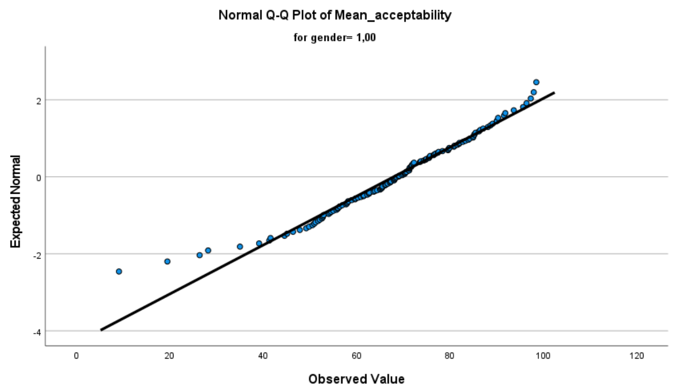

Figure A2

Q-Q plot of Acceptability for Women

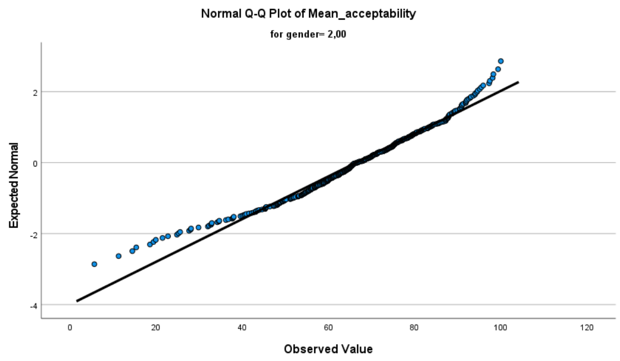

Table A2

Normality of Generation on Acceptability

	Generation	Shapiro-Wilk		
		Statistic	df	Sig.
Acceptability	Generation Z	.977	481	< .001**
	Millenials	.940	43	.026*
	Generation X	.957	67	.020*
	Baby Boomers	.945	22	.247

*p < .05. **p < .001.

Figure A3

Q-Q Plot of Acceptability for Generation Z

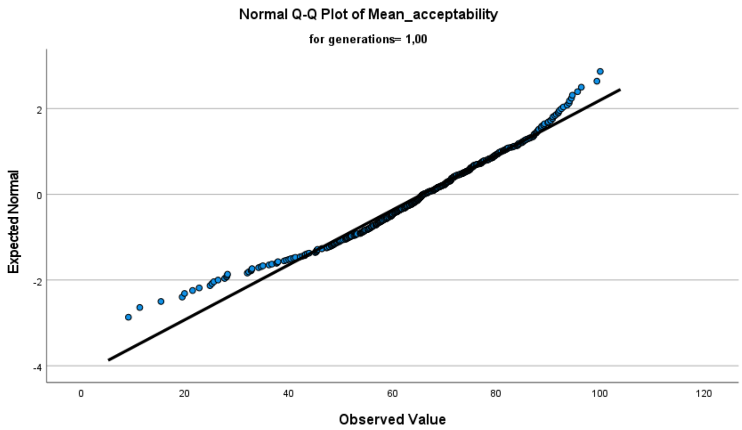

Figure A4

Q-Q Plot of Acceptability for Millenials

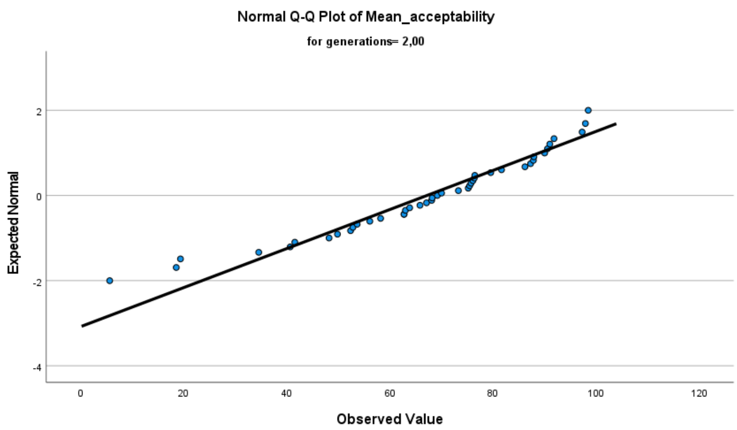

Figure A5

Q-Q Plot of Acceptability for Generation X

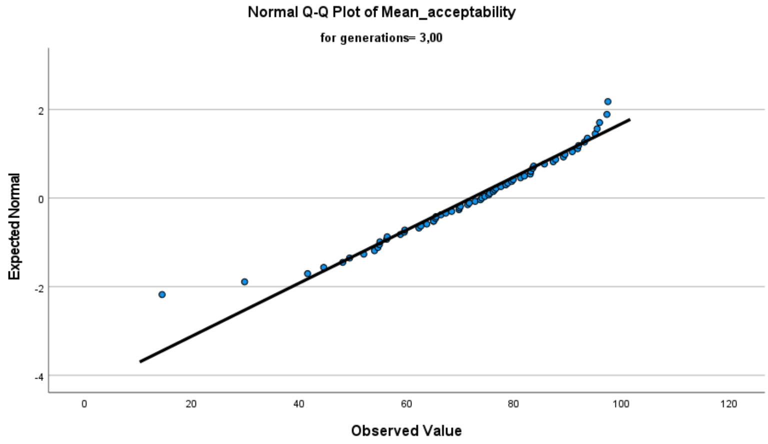

Figure A6

Q-Q plot of Acceptability for Baby Boomers

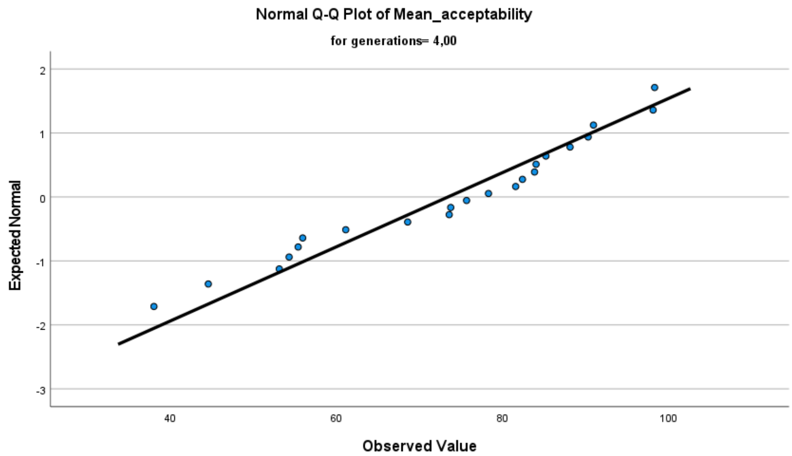

Table A3

Levene's Test of Equality of Error Variances for Acceptability

		Levene Statistic	df1	df2	Sig.
Acceptability	Based on Mean	2.17	7	605	.035*

*p < .05.

Appendix B – Main Analysis of H1

Table B1

Two-Way ANOVA Results for the Effect of Generations and Gender on Acceptability

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power
Generations	2437.53	3	812.51	3.06	.03*	.02	.72
Gender	39.66	1	39.66	0.15	.70	.00	.07
Generations * Gender	923.68	3	307.89	1.16	.33	.01	.32

*$p < .05$.

Table B2

Post-Hoc Test Games-Howell for Acceptability Between Generations

	Mean Difference	Std. Error	Sig.	95% Confidence Interval
Generation Z vs. Millennials	-1.49	3.40	.971	[-10.56, 7.57]
Generation Z vs. Generation X	-6.32	2.16	.02*	[-11.98, -0.66]
Generation Z vs. Baby Boomers	-7.72	3.74	.20	[-18.09, 2.65]
Millennials vs. Generation X	4.83	3.90	.61	[-15.08, 5.43]
Millennials vs. Baby Boomers	-6.23	4.96	.59	[-19.38, 6.93]
Generation X vs. Baby Boomers	-1.40	4.20	.99	[-12.74, 9.94]

*$p < .05$.