Acceptability of Tangible Neurofeedback Companions Across Age and Clinical Status

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Abstract

Introduction: Neurofeedback is a promising intervention for enhancing cognitive functioning and alleviating clinical symptoms through self-regulation of brain activity. However, 30-50% of users are non-responders, indicating the need for more engaging protocols. One proposed solution is a tangible, robot-like learning companion that provides real-time, adaptive feedback. The successful implementation of the agent depends on its feasibility, particularly its acceptability. This study aimed to assess whether the acceptability of the agent varies by clinical status and age group, and whether age influences the impact of clinical status on acceptability.

Methods: An online survey was administered to a convenience sample of 619 adults. Participants were grouped into clinical, subclinical, and healthy, as well as young, middle-aged, and old. The survey included demographic questions, cognitive concerns, personality traits, and acceptability and design preferences of the neurofeedback companion. A two-way ANOVA was used to examine the effects of clinical status and age group on acceptability.

Results: Overall, acceptability was high ($M = 66.56$; $SD = 16.56$). No significant main effects were found for clinical status ($F(2, 610) = 2.01$; $p = .135$) or age ($F(2, 610) = 1.79$; $p = .168$), and no interaction effect emerged ($F(4, 610) = 1.45$; $p = .216$). Acceptability scores remained consistently positive across all groups.

Discussion and Conclusion: Contrary to expectations, neither clinical need nor age influenced the acceptability of the tangible, neurofeedback companion. The findings suggest a broad overall acceptability of the companion, providing a strong foundation for the introduction of the intervention into clinical practice.

Keywords: neurofeedback, tangible neurofeedback companion, feasibility, acceptability, age differences, clinical status

Acceptability of Tangible Neurofeedback Companions Across Age and Clinical Status

Advancements in technology are rapidly transforming healthcare interventions, with digital tools increasingly supporting the treatment of psychiatric disorders (Martínez-Miranda et al., 2019) and cognitive rehabilitation (Park & Ha, 2023). These innovations not only create new treatment approaches, but they also offer the opportunity to enhance the effectiveness of already established protocols. One promising intervention that could benefit from technological refinement is neurofeedback. Neurofeedback involves the self-regulation of brain activity to directly modify the neural mechanisms underlying cognition and behaviour (Enriquez-Geppert et al., 2017; Viviani & Vallesi, 2021). During the protocol, real-time changes in brain activity are recorded, usually through electroencephalography. This data is translated into an online feedback loop, which is presented to the participants through one of the multiple feedback types, namely visual, auditory, or tactile. Positive feedback indicates that the neural activity is moving in the desired direction, whereas negative feedback shows deviation from the intended brain activity, prompting individuals to adjust mental strategies. Through repeated engagement with neurofeedback, participants learn to control specific patterns of brain activity, such as those underlying aspects of cognition or clinical symptoms (Weber et al., 2020; Marzbani et al., 2016). Used both as a therapeutic and a cognitive enhancement tool, neurofeedback responds to a high clinical need for mechanism-driven therapies in neurology and psychiatry (Kadosh & Staunton, 2019). For example, the protocol is applied in the treatment of conditions such as autism spectrum disorder (Kouijzer et al., 2009), epilepsy (Walker & Kozlowski, 2005), attention deficit hyperactivity disorder (Arns et al., 2009), posttraumatic stress disorder (Reiter et al., 2016), as well as for improving executive functioning in healthy adults (Viviani & Vallesi, 2021).

While the intervention has the potential to improve the quality of life of many individuals, a significant proportion of patients do not show improvements

post-neurofeedback sessions. According to Alkoby et al. (2018), 30-50% of the population are considered non-responders. Thus, there is a high need to optimize the protocols in order to maximize their efficacy across diverse populations. Multiple factors can be targeted to address this challenge. Providing adapted feedback, such as supportive social feedback, could improve neurofeedback success (Alkoby et al., 2018). Additionally, actively encouraging individuals to find the most suitable mental strategy might increase performance (Alkoby et al., 2018). Motivation was also found to play a crucial role, with higher motivation levels correlating to better intervention results (Kadosh & Staunton, 2019). Addressing these contributing factors is essential for reducing the proportion of non-responders and improving overall treatment outcomes.

To address these challenges, one innovative strategy is the integration of a tangible, robot-like neurofeedback companion. Learning companions are non-authoritative educational agents, thus promoting a social learning environment (Chou et al., 2003). They serve a key motivational function (Johnson & Lester, 2018), with individuals who have worked with highly proactive and highly responsive agents having better task performance (Kim & Baylor, 2006). Moreover, the physical presence of the tangible agents enhances the learning experience, leading to more engaging training (Johnson & Lester, 2018). In the context of neurofeedback, the learning companion is positioned beside the screen and connected to real-time changes in participants' brain activity. Thus, the protocol provides a great advantage, as access to the constantly updated neural activity enables the agent to provide adaptive feedback. Through this feedback, the companion can offer encouragement and guidance regarding changing or maintaining mental strategies. Additionally, the agent can monitor the performance and track progress throughout the session. Pillette et al. (2020) first introduced such learning companions in the context of Mental-Imagery Brain-Computer Interface User Training. The procedure is closely related to neurofeedback, involving the

modulation of brain activity in order to control external technologies. In this context, the robot-like agent was designed to provide social presence and emotional support through both facial expressions and pronounced sentences, which were in line with the user's performance. The multifaceted feedback was especially beneficial for non-autonomous people, who were disadvantaged by the classic feedback, with sessions with the agent resulting in a higher performance. In addition, the agent improved the user's confidence in their ability to succeed in the protocol (Pillette et al., 2020). The results are highly promising, demonstrating that such companions can enhance the learning process.

While these findings are encouraging, the successful adoption of such interventions depends not only on efficacy (Klaic et al., 2022), but also on their acceptability to the target population. This can be analyzed through feasibility studies, which are centred on forming evidence-based interventions that cater to the needs of potential users (Bowen et al., 2009). A comprehensive framework for feasibility studies was developed by Bowen et al. (2009), which outlines the key areas that should be considered in their development. In this case, one such area entails the acceptability of a specific new approach. Acceptability studies measure whether the new idea is attractive to recipients (Bowen et al., 2009), and have thus become essential when considering the design and implementation of healthcare interventions (Sekhon et al., 2017). According to Grevet et al. (2023), who developed a framework in the context of brain-computer interfaces, a field closely related to neurofeedback, there are three main determinants of acceptability, specifically behavioral intention, perceived ease of use, and perceived usefulness. In the context of neurofeedback companions, the determinants indicate, respectively, the intention to use the agent, the degree of belief that interacting with it would not require effort, and the personal feeling regarding the utility of the companion. Regardless of its clinical promise, if the potential users have negative views towards the

companion, its addition to the trials might be faced with resistance. Therefore, assessing these three determinants would show whether the intervention should be introduced.

The importance of acceptability is particularly pronounced for potential users, who are the individuals that would most likely rely on neurofeedback interventions, either as a symptom alleviating or as a preventative tool. This target group is composed of clinical and subclinical populations. The former includes people who have or suspect a neurological or psychiatric diagnosis, while the latter consists of individuals reporting strong cognitive complaints. The subclinical group is defined in this way because cognitive dysfunction is a transdiagnostic factor related to psychopathology (Abramovitch et al., 2021), and showing such concerns might indicate the need for interventions before a possible disease development (Morovic et al., 2019). A recent systematic review highlighted that the target group is positive towards assistive technologies (Ebuenyi et al., 2023), and digital mental health interventions are generally acceptable to them (Lau et al., 2024). Additionally, as appropriateness, defined as the extent to which the intervention fits the needs of the users, shapes the acceptability of healthcare interventions (Sekhon et al., 2017), potential users may even have more positive attitudes than their healthy counterparts. It is crucial to assess whether neurofeedback companions are similarly well-received, as implementing more effective sessions could not only alleviate symptoms, but also act as a preventative tool for those at risk.

Age is another critical factor that might influence the acceptability of neurofeedback companions. Older adults are generally less open to new technology (Chimento-Díaz et al., 2022). This trend is also present in attitudes towards technology in healthcare, with acceptance decreasing as age increases (Ha & Park, 2020). One possible reason could be limited prior experience (Ezer et al., 2009), as older people use digital tools less than middle-aged individuals, who in turn engage with technology less than younger individuals (Czaja et al., 2006). These attitudes towards technology may shape how different age groups

accept the tangible, robot-like neurofeedback companion, as, in light of prior research, people might become more negative as their age increases.

Given these considerations, there remains a critical gap in the literature regarding how clinical status and age influence the acceptability of the agent. Addressing this gap is crucial for developing interventions that are both effective and tailored to the needs of the potential users. In this sense, not understanding how these factors interact would lead to implementing interventions that are negatively viewed by the groups that would highly benefit from them. In the case that an intervention that is not acceptable is introduced, it could lead to lower efficacy, reduced engagement and motivation, and substantially keep potential users away from a tool with high treatment and prevention potential. Therefore, the present study is guided by the following research question: "Does acceptability of tangible robot-like neurofeedback companions vary by clinical status and age, and does age influence the impact of clinical status on acceptability?".

In line with previous findings, we hypothesize that:

H1a. Clinical and subclinical individuals will report higher acceptability than healthy individuals.

H1b. Acceptability will decrease with age. Younger individuals will report higher acceptability than middle-aged adults, who in turn will report higher acceptability than older adults.

H1c. The effect of user status on acceptability will vary across age groups, with this interaction remaining exploratory.

The null hypothesis states that there are no significant effects of clinical status, age, or their interaction on acceptability.

By investigating these hypotheses, the research aims to address a critical gap in the literature by clarifying how clinical status and age jointly shape the acceptability of tangible,

robot-like neurofeedback companions. The findings will support the advancement of neurofeedback practices, contributing to the development of more inclusive and efficacious interventions.

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.

Experiences, 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 ($\alpha = .83$), confidence in using new technologies is rated more poorly ($\alpha = .57$).

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.

Data preparation

Prior to running the analysis, the data were cleaned and prepared. Those who did not complete the full questionnaire or selected "I prefer not to say" regarding psychiatric or neurological conditions were excluded from the analysis. Thus, 619 participants remained in the sample. A composite acceptability score was computed as the mean of the eleven acceptability questionnaire items. Participants were split into three age groups, namely younger (18-39), middle-aged (40-59), and older adults (60+), following the age categorization used for predicting use of technology across the lifespan (Czaja et al., 2006). They were also assigned to either healthy, subclinical or clinical groups. The former is composed of people with no diagnosis and no strong cognitive complaints. The subclinical group includes those who indicated at least one cognitive complaint as "Yes, strongly", but do not have or suspect a diagnosis. The clinical group contains individuals with suspected or diagnosed conditions.

Statistical Analysis

A two-way between-subjects ANOVA was conducted to examine the effect of age and clinical status on acceptability scores. Both independent variables were between-subjects factors. Clinical status had three levels, namely healthy, subclinical, and clinical. Age group also had three levels: young (18-39), middle-aged (40-59), and older adults (60+).

If a main effect of clinical status was found, the direction of the hypothesis would be examined through planned comparisons with simple contrasts. To investigate potential patterns across the three age brackets, polynomial contrasts would be applied if the main effect of age was significant. In the event of a significant interaction, pairwise comparisons with Bonferroni correction would be used to examine group differences at each level of the interacting variables.

Before testing the hypotheses, the normality and homogeneity of variances assumptions were assessed. The normality of the standardized residuals of the acceptability score was checked using the Shapiro-Wilk test, while the homogeneity of variances was evaluated using Levene's test. Cook's Distance was calculated for each case in order to check for influential observations. The significance threshold was set at $\alpha = .05$. The statistical analysis was conducted using IBM SPSS Statistics (Version 30).

Results

Out of the 619 participants, the final sample included 506 younger, 85 middle-aged, and 28 older adults. In terms of clinical status, there were 147 clinical, 133 subclinical, and 339 healthy individuals. The mean age was 27.54. Overall, the results indicate high acceptability scores across all groups, $M = 66.56$ ($SD = 16.56$). The number of participants within each age and clinical status group combination, as well as the means and standard deviations of their acceptability scores, are presented in Table 1. A visual representation of the means and standard deviations can be seen in Figure 1. Among healthy participants, the mean acceptability scores were lower in the younger group (M (SD) = 65.61 (15.73)) than in the two older age brackets (middle-aged: M (SD) = 74.31 (17.85); old: M (SD) = 74.08 (18.02)). In contrast, within the clinical and subclinical groups, no patterns in the acceptability scores were observed. Moreover, younger individuals reported a somewhat similar score irrespective

of their clinical status, while healthy older and middle-aged adults indicated a higher acceptability than their clinical and subclinical counterparts (see Table 1).

Table 1

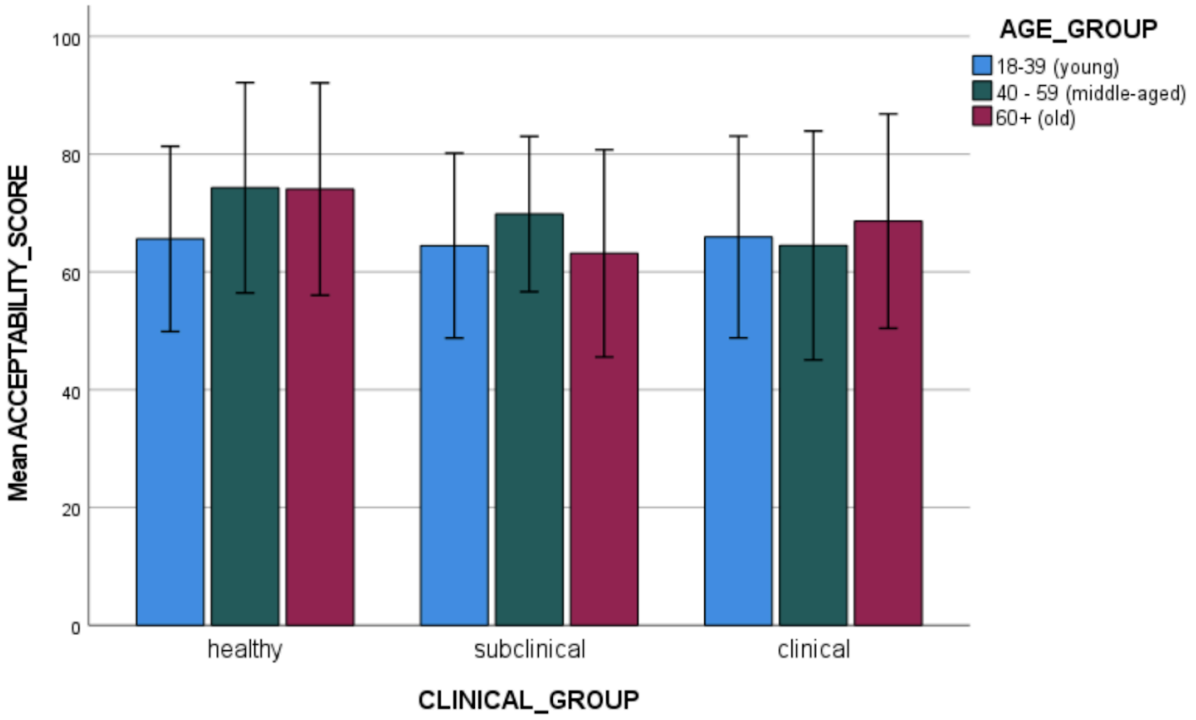
Descriptive Statistics for Acceptability Scores by Clinical Status and Age

Group	Age Group	M (SD)	N
Healthy	Young	65.61 (15.73)	263
	Middle-aged	74.31 (17.85)	57
	Old	74.08 (18.02)	19
Subclinical	Young	64.48 (15.70)	118
	Middle-aged	69.84 (13.19)	10
	Old	63.16 (17.60)	5
Clinical	Young	65.94 (17.14)	125
	Middle-aged	64.5 (19.43)	18
	Old	68.64 (18.20)	4

Note. Age groups are defined as young = 18-39, middle-aged = 40-59, and old = 60+.

Figure 1

Bar Plot of Mean Acceptability Scores by Clinical Status and Age



Note. The error bars represent ± 1 standard deviation.

The Shapiro-Wilk test applied to the standardized residuals of acceptability scores indicated that the normality assumption was not met ($W = 0.97$, $p < .001$). Visual inspections of Q-Q plots indicated minor deviations from normality, particularly at the tails. Levene's test was non-significant, $F(8, 610) = 0.58$, $p = .791$, confirming the homogeneity of variances. All Cook's Distance values were below 1, suggesting the absence of influential observations. ANOVA is generally robust to non-normality, especially if the homogeneity of variances is met (Blanca et al., 2017). Therefore, despite violating the normality assumption in most subgroups, the analysis was continued with parametric testing.

A two-way ANOVA was conducted to examine the effects of clinical status (healthy, subclinical, clinical) and age groups (18-39, 40-59, 60+) on acceptability. We hypothesized that clinical and subclinical individuals would have a higher acceptability than healthy

participants (H1a), age would decrease with age across the three groups (H1b), and age and clinical status would interact in shaping attitudes towards the companion (H1c). It is important to note that, while key assumptions were met, the oldest age bracket within subclinical and clinical groups had very small sample sizes, respectively, $n = 5$ and $n = 4$. While this may limit the power of the analysis in these subgroups, the cells were retained to maintain the real-world demographic distributions displayed in technology use studies (Czaja et al., 2006). The results revealed that the main effect of clinical status on acceptability scores was not significant, $F(2, 610) = 2.01$, $p = .135$, partial $\eta^2 = .007$, disconfirming the hypothesis H1a. Similarly, the hypothesis H1b was not supported, as a non-significant main effect of age group was observed, $F(2, 610) = 1.79$, $p = .168$, partial $\eta^2 = .006$. Thus, no significant difference in acceptability was found across age brackets and clinical status. The interaction between clinical status and age group was also not statistically significant, $F(4, 610) = 1.45$, $p = .216$, partial $\eta^2 = .009$. Therefore, the interaction hypothesis H1c was not confirmed, as the effect of clinical status on acceptability did not differ across age groups. Given that none of the effects were statistically significant, no post hoc tests were applied.

Discussion

Tangible robot-like neurofeedback companions are an emerging intervention designed to improve performance in neurofeedback. The present study examined whether clinical status and age group influence the acceptability of this innovation. The topic is particularly relevant due to the crucial role of user acceptability in the adoption of healthcare interventions (Sekhon et al., 2017). Using convenience sampling, we collected data from 619 participants, who were categorized into three clinical status groups (healthy, clinical, and subclinical) and three age groups (young, middle-aged, and older adults). We hypothesized that individuals with clinical and subclinical status would have a higher acceptability than their healthy counterparts (H1a), that acceptability would decrease with age (H1b), and that the effect of

clinical status on acceptability would vary across age groups (H1c). However, despite our expectations, the data did not support the hypotheses. These findings challenge previous assumptions, with the high overall acceptability suggesting that the agents may be generally acceptable irrespective of age and clinical background. In the following sections, we will consider possible explanations for the absence of variability in acceptability across the target groups, explore the implications for further neurofeedback practices, and reflect on the study's limitations and future directions.

Acceptability of Tangible Neurofeedback Companion by Clinical Status

As opposed to what we proposed in H1a, clinical and subclinical participants did not differ in their acceptability of the neurofeedback agent when compared to the healthy individuals. The basis for the expected directionality stemmed from the idea that a higher perceived appropriateness would lead to more positive attitudes (Sekhon et al., 2017). One possible explanation is that healthy participants might have been more receptive than expected. As neurofeedback is also used for cognitive enhancement in healthy individuals (Viviani & Vallesi, 2021), they might have perceived the companion as an important addition for reaching mental optimization, despite having no clinical need. Another reason could be that counterbalancing factors are present in the (sub)clinical population, leveling the differences we expected across groups. For instance, clinical and subclinical groups may experience greater cognitive load when introduced to a new intervention, as stressors associated with illnesses might affect engagement with complex tasks (Antonio et al., 2023). Additionally, certain conditions, such as ADHD or ASD, involve sensory sensitivities. They can be present as both hyper- and hypo-reactivity to sensory stimuli, and can affect the outcome of robot therapies (Chevalier et al., 2022). Moreover, neuropsychiatric disorders are marked by social withdrawal as an early manifestation symptom (Oliva et al., 2021). As learning companions are designed to promote a social learning environment (Chou et al.,

2003), including the agent in the intervention might go against their disengagement with such interactions. Lastly, if engaging with the neurofeedback companion is perceived as a marker of even greater impairment, the presence of the agent might reinforce self-stigma, which, in turn, may lead to decreases in self-esteem and self-efficacy (Jahn et al., 2020). Together, these factors present possible reasons behind the similar acceptability scores, as they might have leveled the more positive attitudes that we expected in the clinical and subclinical populations.

While these aspects are worth considering, it is essential to note that overall ratings of all groups were high, indicating that the companion was generally well-received. Thus, while the previously stated factors might affect users individually, the agent is seen as a beneficial addition to neurofeedback irrespective of clinical status. Nonetheless, identifying what mitigates potential stressors and implementing the companion in line with the diverse emotional and perceptual needs of clinical and subclinical users may further enhance its acceptability. In a broader sense, these findings offer valuable insights relevant to clinical psychology and neuropsychology, particularly regarding the use of digital agents in therapeutic settings. Given the generally high acceptance of the neurofeedback companions, attitudes towards integrating such tools into other healthcare practices should be further explored, as they might be similarly well-received.

Acceptability of Tangible Neurofeedback Companion by Age

In terms of age, contrary to our hypothesis H1b, there is no difference in acceptability scores between younger, middle-aged, and older adults. The results are not consistent with previous research, which suggests that older adults are less open to new technologies, due to factors such as reduced exposure (Ezer et al., 2009). One possible explanation could be that healthcare technology, such as the tangible neurofeedback companion, might be viewed differently than general digital tools. As health concerns are associated with aging (Deeks et

al., 2009), and high perceived health risks lead to higher engagement in health-enhancing behaviors (Ahadzadeh et al., 2015), older adults might overcome technophobia when it comes to the health domain (Smrke et al., 2024). Additionally, another reason behind the lack of variability in acceptance might stem from the design. Older adults have more negative attitudes towards technology if they perceive certain features as unhelpful, or if they see it as inconveniencing (Mitzner et al., 2010). Thus, the high acceptability might be a result of the fact that the design of the tangible, neurofeedback companion is already seen as useful and accessible, irrespective of age. Therefore, the findings support the integration of the agent in neurofeedback, and informs other healthcare practices that properly designed, health-focused technologies can appeal to users across all life stages.

Variation in Acceptability by Clinical Status across Age Groups

Contrary to our expectations, the difference in acceptability between healthy, subclinical, and clinical individuals remained consistent across the three age brackets. As previously discussed, the effect of the high perceived appropriateness in subclinical and clinical individuals, as well as the lower openness to technology in the older participants, may have been overridden by counteracting factors, such as increased cognitive load in the former group, and perceiving the companion as healthcare technology in the latter group (Sekhon et al., 2017; Chimento-Díaz et al., 2022; Antonio et al., 2023; Smrke et al., 2024). This might have impeded the emergence of differences across the subgroups, resulting in the lack of interaction. Nevertheless, the consistently high scores suggest that the proposed design and implementation of the companion might have catered equally to all participants, with the function of the neurofeedback agent resonating broadly with users of all backgrounds.

Theoretical and Practical Implications

The findings of this study offer crucial insights into current theoretical assumptions about the role of age and clinical status in shaping perceptions of digital health tools. While

prior research highlighted that older individuals have a lower technology acceptability, and clinical and subclinical participants show a higher receptiveness, the uniform acceptability scores indicate a more complex picture. The results imply that the influence of the two demographics might be mitigated by other factors. In the case of the clinical and subclinical populations, aspects such as social withdrawal (Oliva et al., 2021) and lower self-efficacy caused by cognitive load, sensory processing issues, or internalized stigma (Antonio et al., 2023; Chevalier et al., 2022; Jahn et al., 2020), may impact the expected higher positive attitudes. On the other hand, motivation to engage in health-supportive behavior might counterbalance technophobia (Smrke et al., 2024). Thus, user acceptance cannot be predicted by clinical status and age alone. Instead, broader models of acceptability should consider more factors, such as the specific framing of the intervention, in the case of health-oriented tools, and perceived self-efficacy.

The practical value of the study stems from the high, consistent acceptability of the tangible, neurofeedback companions across diverse groups. In this sense, our results imply that the agent is already appealing to many individuals. Therefore, further steps can be taken to implement it in the neurofeedback protocols. Additionally, the lack of age differences in acceptability further informs against age-related biases, as clinicians were found to be less likely to recommend digital tools to older individuals due to ageist attitudes (Mannheim et al., 2023). Thus, our study highlights that such interventions are appealing to all groups and should therefore be recommended to users of any age.

Strengths

The study is the first to explore the acceptability of tangible, neurofeedback companions, informing future practices of an appealing alternative to the classic, abstract feedback seen in the protocols. In addition, it employs a large and diverse sample of 619 participants, enhancing the applicability of the findings. Moreover, by including the

subclinical population, which is often overlooked, it provides a more nuanced understanding of the attitudes towards the agents. As even subclinical symptoms may affect brain structure (Besteher et al., 2017), accounting for the views of people who may highly benefit from neurofeedback is highly relevant. Lastly, by focusing on acceptability, a critical step in clinical implementations is explored. Together, these strengths offer crucial insights into how different users perceive the tangible, neurofeedback companion, contributing to the development of technologies that are not only functional, but also well-received by the target population.

Limitations and Future Directions

Despite the strengths and the novel contributions of the study, multiple limitations should be accounted for. The use of convenience sampling might have attracted participants who may already be more open to healthcare technology interventions. This could inflate the acceptability scores, limiting the generalizability of the findings to less accepting populations. Additionally, the sample is highly skewed towards younger adults, with the mean age being 27. In contrast, there were very few clinical and subclinical participants who belonged to the oldest age bracket. This demographic imbalance might have impeded the emergence of an age effect. For instance, the attitudes of older individuals suffering from a condition may not have been accurately represented in the study. Moreover, the participants self-reported their acceptability based on a description of the neurofeedback companion rather than direct interaction. While this is the proper approach for early-stage feasibility research, it only captures anticipated attitudes, which may not be in line with the experienced ones.

To address the limitations, future research should prioritize a more diverse sampling strategy, perhaps by partnering with aging-focused organizations or caregiver networks. Qualitative approaches, such as interviews and focus groups, may also provide deeper insights into the needs and concerns of the diverse groups. Especially if applied after the

real-life interaction with the neurofeedback companion, they may reveal important input regarding the ease of use and perceived barriers that can be used in further development of a user-centered design. This may be especially relevant in the clinical and subclinical groups, who might face challenges such as cognitive burden, or decreased self-efficacy. Lastly, longitudinal research should be conducted to assess whether the acceptability of the neurofeedback companions evolves over repeated exposure. In this sense, certain users may initially respond with skepticism, but become more receptive as trust or familiarity develops. Understanding this trajectory is key to encouraging sustained engagement with the neurofeedback agent.

Conclusion

The study is the first to investigate the acceptability of a tangible, robot-like neurofeedback companion across different age groups and clinical statuses. Contrary to what we expected, acceptability did not vary across groups. The results challenge the idea that factors such as age-related technophobia or increased clinical need directly influence the openness to such healthcare technologies. Instead, they point to a more complex interplay, where perceived relevance and emotional and perceptual needs may outweigh the demographic predictors. All in all, the high, consistent acceptability across the sample indicates a promising direction in terms of the enhancement of the neurofeedback protocols. While future applications should still consider individual needs and potential barriers, the findings show that the agent can be accepted by a wide range of users. Thus, our findings provide a strong foundation for the introduction of tangible, robot-like neurofeedback companions into clinical practice.

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Appendix

Table 1

Descriptives of Acceptability Score and Age

	N	Mean (SD)
Acceptability score	619	66.56 (16.56)
Age	619	27.54 (14.46)

Table 2

Test of Normality for Standardized Residuals of Acceptability Score

	Shapiro-Wilk		
	Statistic	df	Sig.
Standardized residuals for acceptability scores	.97	619	<.001

Note. The Shapiro-Wilk test indicates that the residuals significantly deviate from normality ($p<.001$).

Figure 1

Q-Q plot for Standardized Residuals of Acceptability Score

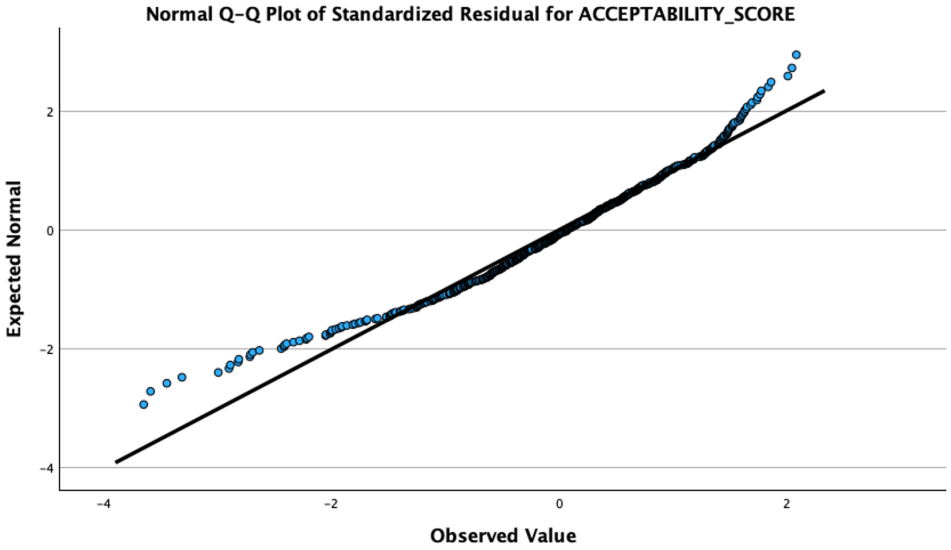

Table 3

Levene's Test of Equality of Error Variances

		Levene Statistic	df1	df2	Sig.
Acceptability Score	Based on Mean	.58	8	610	.791
	Based on Median	.51	8	610	.852
	Based on Median and with adjusted df	.51	8	597.20	.852
	Based on trimmed mean	.56	8	610	.810

Note. Lavene's test indicates that the homogeneity of variances was met (p = .791).

Table 4

Descriptive Statistics for Cook's Distance Values

	N	Mean (SD)	Minimum	Maximum
Cook's Distance	619	.001 (.007)	.00	.11

Note. Cook's Distance values were calculated for each acceptability score. Values below 1 are generally considered acceptable, suggesting that no case had an unwarranted influence on the model.

Table 5

Two-way ANOVA of Clinical Status and Age Group on Acceptability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	5547.84	8	693.48	2.58	.009	.033
Intercept	535581.79	1	535581.79	1992.83	<.001	.766
Clinical Status	1081.85	2	540.93	2.01	.135	.007
Age Group	962.29	2	481.15	1.79	.168	.006
Clinical Status * Age Group	1557.42	4	389.36	1.45	.216	.009
Error	163940.48	610	268.75			
Total	2911657.21	619				
Corrected Total	169488.32	618				