

Age Differences in Flow Experience During Virtual Reality Rehabilitation Tasks: A Cross-Sectional Study

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Abstract

Background: Virtual reality (VR) is increasingly applied in rehabilitation training. Flow experience, a critical factor for enhancing user engagement and training efficacy, exhibits age-related differences that are essential for designing elderly-friendly rehabilitation tasks. However, current VR rehabilitation systems often overlook age-related subjective experience disparities, leading to insufficient engagement among older adults.

Objective: This study aims to explore differences in flow experience between younger and older adults during identical VR rehabilitation tasks and provide empirical evidence for designing personalized elderly rehabilitation programs.

Methods: We recruited 21 older adults (mean age: 63.00 ± 6.64 years, 10 males) and 19 younger adults (mean age: 24.68 ± 1.16 years, 9 males). Participants performed the "Space Pop" task in Kinect Adventures (simulating limb coordination training) using VR. Flow experience was measured using the Chinese version of the Flow State Scale-2 (CFSS-2). Group differences were analyzed via Wilcoxon rank-sum tests.

Results: Older adults exhibited significantly lower overall flow experience than younger adults ($p < 0.001$, $d = 1.45$), with significant differences in the dimensions of "challenge-skill balance" ($p < 0.001$), "clear goals" ($p = 0.044$), "sense of control" ($p < 0.001$), and "loss of self-consciousness" ($p = 0.048$). Other dimensions (e.g., concentration, time transformation) showed no statistical differences.

Conclusions: Age significantly impacts flow experience in VR rehabilitation tasks. Tailoring designs through dynamic difficulty adjustment, intuitive goal cues, and reduced motor demands can enhance older adults' control, immersion, and active participation, thereby improving health outcomes.

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Original Manuscript

Original Paper

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Abstract

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Keywords: flow; virtual reality; task design; age differences

Introduction

Role of Flow Experience in VR Rehabilitation

"Flow" is a "best experience" where individuals are fully engaged in challenging activities, experiencing high focus, control, and enjoyment[1]. Due to its positive effects, flow has been widely applied in sports, music, gaming, learning, and other fields[2–5], enhancing performance, engagement, and task completion.

In VR rehabilitation, flow's characteristics are particularly important. VR's 3I features (immersion, interaction, imagination) and multi-sensory stimulation theoretically offer better immersive experiences than traditional devices, aiding skill improvement and rehabilitation through simulated scenarios[6]. However, despite advancements in VR hardware, rehabilitation task design has failed to effectively incorporate engagement mechanisms and individual adaptation, leading to poor subjective experiences[7–9]. Current tasks often use universal designs, ignoring age-related differences in subjective experiences caused by older adults' cognitive decline and motor ability reduction, which affects training compliance. Flow theory, as a key framework for measuring subjective experience, can assess the positive experiences users gain from VR tasks[10], guiding task optimization.

Theoretical Basis for Age-Related Flow Differences

Flow is influenced by individual differences, including personality traits, gender, motivation, and mental health[2,11–14]. Élise et al.[15] showed that VR scene types, sequences, and player traits significantly affect flow. Age, a critical factor in psychological experiences, may influence flow in VR. Murman et al.[16] noted that cognitive abilities (e.g., information processing speed, executive function) decline with age, and Gazzaley et al.[17] highlighted older adults' difficulties in attention allocation and maintenance. Boot et al.[18] found older adults have less video game experience and different preferences from younger individuals. These cognitive, attentional, and preference changes may impact their flow experience in VR tasks. Older adults may face challenges in achieving flow due to cognitive and motor declines, but empirical research on age differences in VR rehabilitation flow is scarce, especially for tasks like limb coordination training.

Research Objectives and Hypotheses

This study compared nine-dimensional flow experiences between young and older adults in VR rehabilitation tasks to test the hypothesis that age differences affect flow experience, aiming to:

1. Identify key dimensions of age-related flow experience differences;
2. Provide theoretical evidence for adapting task difficulty and optimizing interfaces for older adults, promoting VR rehabilitation design.

Methods

Participants

Forty healthy participants were recruited and divided into an older adult group (21 participants, mean age: 63.00 ± 6.64 years, 10 males) and a young adult group (19 participants, mean age: 24.68 ± 1.16 years, 9 males). Inclusion criteria were: normal or corrected-to-normal vision, no neuromuscular diseases, no prior experience with Kinect, and the ability to complete questionnaires independently. All participants were briefed on the study objectives and procedures and provided written informed consent before participation. The study was approved by the Science and Ethics Committee of the School of Engineering Medicine, Beihang University (Ethics ID: BM20230154).

Experimental Tools

The experimental equipment included an Xbox 360 gaming console, a Kinect v1 sensor, and a 28-inch 4K display (Samsung U28E590D). The rehabilitation task selected was "Space Pop" from Kinect Adventure, which required participants to control a virtual character to pop bubbles through limb movements (forward/backward/left/right) and arm actions (flapping/dropping). Real-time scores and ranks (none, bronze, silver, gold, platinum) were displayed, with the task goal of popping as many bubbles as possible to simulate limb coordination and reaction speed training in rehabilitation.

The Flow State Scale (FSS-2) [19] was adapted into the Chinese version (CFSS-2) through translation and back-translation. The scale consists of 9 dimensions (36 items). The Cronbach's α coefficient for the scale ranged from 0.83 to 0.98 (total scale $\alpha = 0.86$), with item factor loadings between 0.44 and 0.98 (mean factor loading = 0.87), indicating satisfactory internal consistency and cross-cultural, cross-domain applicability.

Experimental Procedure

Before the experiment, the Kinect sensor was calibrated for optimal recognition, and participant positioning was adjusted to the recommended distance (2–3 meters from the display) within the Kinect's effective range. Participants completed a 10-minute training session (repeating the task twice) to ensure familiarity with the task operations, followed by a 2-minute rest to restore physical stamina. The formal task lasted 4–6 minutes (mean: 5 minutes). After task completion, participants immediately completed the CFSS-2 questionnaire based on their experience during the task. The questionnaire used a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), with instructions provided at the top to emphasize that there were no right or wrong answers. Participants took an average of 1.2 minutes to complete the questionnaire after the task. The experiment was terminated immediately if any participant reported physical discomfort. The experimental procedure is outlined in Figure 2.

Data Collection and Analysis

Forty questionnaires were collected (100% response rate). For each questionnaire, the mean score of the 4 items in each dimension was calculated as the dimension score, and the mean score of all items in the questionnaire was calculated as the participant's flow experience score during the task.

Using R version 4.3.3, normality tests (Shapiro-Wilk test) and homogeneity of variance tests (Levene's test) were performed for the older and younger groups. If data met both normality and homogeneity of variance criteria, independent sample t-tests were used to analyze significant differences in overall flow experience and its dimensions between the two groups. If either criterion was not met, the nonparametric Wilcoxon rank-sum test was applied to examine significant differences in flow experience, with a significance level set at $\alpha=0.05$.

Results

Due to the data not conforming to normal distribution and homogeneity of variance, we employed the Wilcoxon rank-sum test (the non-parametric equivalent of the independent sample t-test) for between-group comparisons ($\alpha=0.05$). Effect size was calculated using the corrected Cohen's d (Hedges' g), and 95% confidence intervals were estimated via the Bootstrap method to enhance the robustness of the results. The analysis revealed significant differences between the older and younger groups in overall flow experience and several dimensions (Table 1). A radar chart was plotted to further analyze the differences in the mean flow scores between the two groups (Figure 3), showing that younger adults scored higher than older adults in most dimensions (except for Time

transformation and Autotelic experience).

For overall flow experience, there was a significant difference between the older and younger groups ($W = 339.5$, $p < 0.001$), indicating that older and younger adults obtain different flow experiences in the same VR task, with the flow distribution among older adults being more concentrated (Figure 4). The effect size was large ($d=1.45$, $\eta^2 = 0.37$), suggesting a substantial impact of age on overall flow experience.

Regarding different flow dimensions (Figure 5), significant age differences were found in four dimensions: challenge-skill balance ($W = 339$, $p < 0.001$, $d = 1.28$, $\eta^2 = 0.31$), clear goals ($W = 271$, $p = 0.044$, $d = 0.65$, $\eta^2 = 0.10$), sense of control ($W = 389.5$, $p < 0.001$, $d = 3.22$, $\eta^2 = 0.74$), and loss of self-consciousness ($W = 268$, $p = 0.048$, $d = 0.57$, $\eta^2 = 0.08$). Among these, the sense of control dimension had the largest effect size ($\eta^2 = 0.74$).

Other dimensions such as action awareness ($p = 0.065$, $d = 0.73$, $\eta^2 = 0.13$) and unambiguous feedback ($p = 0.091$, $d = 0.69$, $\eta^2 = 0.12$) had p-values close to the significance threshold, with effect size indicators suggesting a possible weak influence, but they did not reach statistical significance. No significant age differences were observed in concentration ($p = 0.619$, $d = 0.12$, $\eta^2 < 0.01$), time transformation ($p = 0.481$, $d = -0.12$, $\eta^2 < 0.01$), and autotelic experience ($p = 0.632$, $d = -0.25$, $\eta^2 = 0.02$), with small effect sizes.

Table 1. Results of age differences in flow experience.

Dimensions	W Value	P Value	Cohen's d
Challenge-skill balance	339	<0.001*	1.28
Action awareness	267	0.065	0.73
Clear goals	271	0.044	0.65
Unambiguous feedback	256	0.091	0.69
Concentration	182.5	0.619	0.12
Sense of control	389.5	<0.001*	3.22
Loss of self-consciousness	268	0.048	0.57
Time transformation	224	0.481	-0.12
Autotelic experience	181.5	0.632	-0.25
Total	339.5	<0.001*	1.45

Discussion

The goal of this study was to investigate whether age factors affect flow experience in VR tasks. We observed significant differences in flow experience between older and younger adults in the set VR task, which may be related to age-related physiological and psychological changes.

The perceived match between task challenge and personal skill among older adults was significantly lower than that among younger adults ($p < 0.001$, $\eta^2 = 0.31$), meaning older adults perceived task challenges as either higher or lower than their own skills, resulting in a low match between challenge and skill. Multiple meta-analyses have shown that physical activity levels have a protective effect on cognitive function[20-22]. Older adults generally experience brain function degradation due to reduced physical activity[23]. Especially when task challenges increase, the activation level of brain regions in older adults is equivalent to or lower than that in younger adults, with poorer behavioral performance[24]. Additionally, the complexity of motor tasks (such as those requiring high coordination) places more demanding cognitive requirements on older adults, leading to more obvious cognitive decline. We speculate that cognitive differences and objective physical conditions between older and younger adults may contribute to the differences in the challenge-skill balance

dimension.

In the clear goals dimension, older adults scored significantly lower than younger adults ($p = 0.044$, $\eta^2 = 0.10$), indicating they had more difficulty clearly perceiving task goals during the task. This may be related to the decline in cognitive abilities and task comprehension in older adults. With age, individuals experience slower information processing and reduced attention maintenance, making it harder for them to quickly understand and internalize task goals. Research has shown that older adults process information more slowly, which may lead to poor performance in tasks requiring rapid target recognition and response[25]. Furthermore, older adults' perception of task goals may be more influenced by situational factors, such as the complexity of visual information and the clarity of cues, which may further affect their goal perception in VR tasks. Studies have shown that in visual search tasks, if the target presentation time is short or there are many interfering factors, older adults may have difficulty clearly perceiving the target[26].

Older adults had significantly lower sense of control over the task than younger adults ($p < 0.001$, $\eta^2 = 0.74$), meaning they were less likely to feel a sense of mastery over the task, and the difference in this dimension was the most significant. This result supports the findings of Hibbs et al.[27], who found that older adults had weaker sense of control than younger adults in low-screen VR conditions, and our study further confirms the significance of this result. This may be related to the objective physical and psychological conditions of older adults. On the one hand, due to the decline in motor abilities, older adults may feel limited control over tasks that require rapid response or fine motor control, affecting their sense of task mastery. Research has shown that older adults exhibit reduced accuracy, increased variability, and prolonged execution time when performing bimanual motor tasks, failing to achieve expected performance[28]. On the other hand, older adults may experience more anxiety or lack confidence in task completion when faced with new tasks[29]. This decline in self-efficacy may affect their sense of control over tasks. Especially when faced with new or complex tasks, older adults may doubt their abilities, leading to a lower sense of control. As people enter old age, physical functions and activity abilities gradually decline, and psychological characteristics also change[30]. Due to reduced sensory abilities, slower neuromotor speed, and memory decline, older adults become more cautious. We believe that the decline in physical activity abilities and self-efficacy may be the reasons why older adults have lower sense of control than younger adults in games.

The loss of self-consciousness dimension showed that older adults scored significantly lower than younger adults ($p = 0.048$, $\eta^2 = 0.08$), indicating they had more difficulty fully immersing and experiencing self-forgetfulness in VR tasks. Many older adults have less experience and proficiency with emerging technologies, which may become a barrier to their integration into VR environments[31]. Research has shown that there are differences in the sense of immersion in VR among different age groups, which may be related to motor performance and subjective experience[27]. Inattention or memory loss in older adults may lead to poor motor performance and concerns about task failure or mistakes, making it difficult for them to fully engage in the VR experience and maintaining a high level of self-awareness.

Therefore, older adults differ from younger adults in flow experiences related to challenge-skill balance, clear goals, sense of control, and loss of self-consciousness, possibly due to declines in cognitive abilities, objective physical strength, and self-efficacy. In contrast, younger adults can more easily adapt to task challenges, maintaining high goal perception, sense of control, and immersion. This finding provides important insights for VR task design. Designers should adjust task difficulty, operation methods, and feedback mechanisms according to the characteristics of different age groups, especially enhancing older adults' sense of control and immersion to improve their flow

experience. First, in task design, the challenge level should be adjusted to ensure that older adults can experience a match between skills and challenges within an appropriate difficulty range. In the task operation interface, more explicit goal guidance is needed, such as visual cues and task decomposition, to help older adults understand task goals. Additionally, task operation methods can be optimized, such as reducing high requirements for rapid response and fine motor control, and enhancing self-efficacy through positive feedback.

It is worth noting that in this study, dimensions such as action awareness ($p=0.065$, $\eta^2 = 0.13$), unambiguous feedback ($p=0.091$, $\eta^2 = 0.12$), concentration ($p=0.619$, $\eta^2 < 0.01$), time transformation ($p=0.481$, $\eta^2 < 0.01$), and autotelic experience ($p=0.632$, $\eta^2 = 0.02$) did not show significant age differences. Among them, the first two had p -values close to the statistical threshold (0.05), and the effect sizes were close to medium levels. Although they did not reach significance, increasing the sample size in the future may further reveal potential differences. The low effect sizes in concentration, time transformation, and autotelic experience suggest that these flow characteristics may be more universal. The consistency in the concentration dimension may be related to the intuitiveness of task design, where the task's low cognitive load and situational attractiveness allow older adults to maintain high focus. The lack of differences in time transformation may be due to the short task duration (average 5 minutes), where differences in time perception between older and younger adults may not have been fully reflected. The consistency in autotelic experience reflects the universal appeal of the task's fun design, which provides similar intrinsic motivation for different age groups[32]. The statistical power of this study (Power=0.82) indicates that the sample size is sufficiently sensitive to detect medium and above effect sizes ($\eta^2 \geq 0.06$). Therefore, the low effect sizes ($\eta^2 < 0.02$) in concentration, time transformation, and autotelic experience are more likely to reflect true commonalities between age groups rather than insufficient statistical power. For the action awareness ($p=0.065$) and unambiguous feedback ($p=0.091$) dimensions close to the significance threshold, their medium effect sizes ($\eta^2=0.12-0.13$) suggest that a larger sample size may be needed to confirm potential differences in these dimensions.

The limitations of this study include the task-dependent impact of age on flow experience. Future research can further explore the mechanism by designing longer task durations and increased complexity. Additionally, the sample range of this study was narrow, only covering older and younger adults without considering middle-aged or other age groups. At the same time, the task type in the study was relatively single. Future research can expand to different types of virtual reality tasks and consider broader individual differences (such as gender, personality traits, etc.) on flow experience to meet the personalized needs of VR rehabilitation task design.

Conclusions

This study is the first to empirically demonstrate significant differences in flow experience between older and younger adults during VR rehabilitation tasks, primarily reflected in dimensions closely related to challenge-skill balance and sense of control, which are intertwined with motor function and cognitive ability. The findings provide critical strategies for designing VR rehabilitation programs for older adults: enhancing their sense of control and immersion through technical adaptation and optimized task guidance can effectively promote active participation, laying a foundation for the application of VR in promoting elderly health. Future research should further explore the integration of multi-modal interventions and personalized algorithms to advance the precision development of rehabilitation technology.

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Tong was responsible for the study design, data collection, data analysis, and manuscript writing. Li

mainly recruited participants and assisted with data collection. Zhang provided feedback on the introduction and discussion sections of the manuscript and played a key role in interpreting the results and guiding the discussion. Pu and Ren jointly participated in the study design and oversaw and coordinated the entire research process. All authors contributed to revising and approving the final manuscript.

Conflicts of Interest

None declared.

Abbreviations

VR: virtual reality

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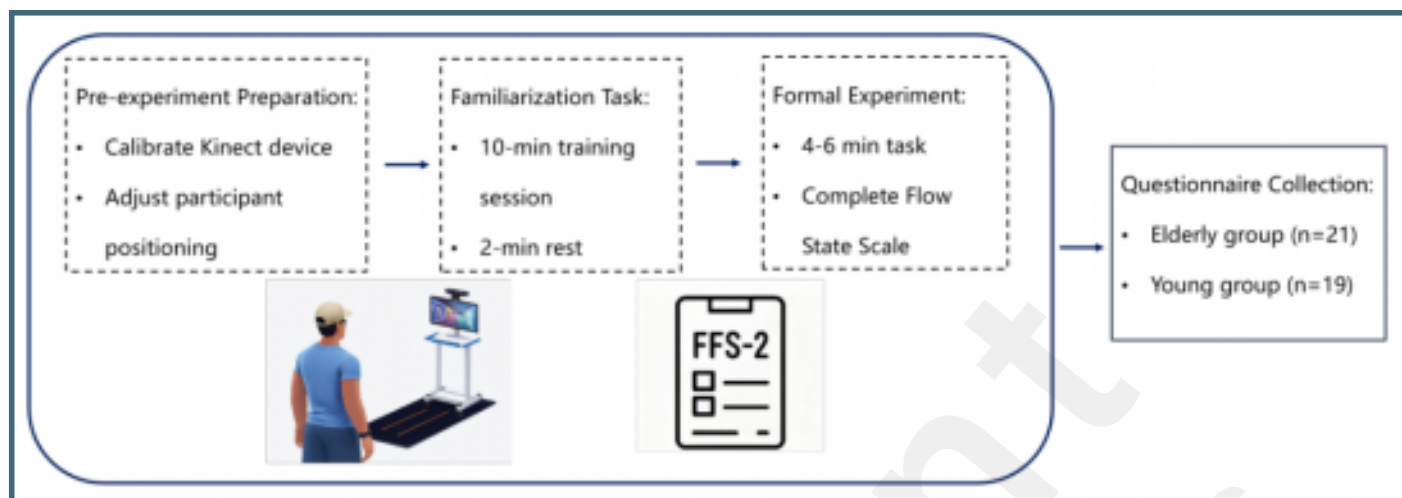
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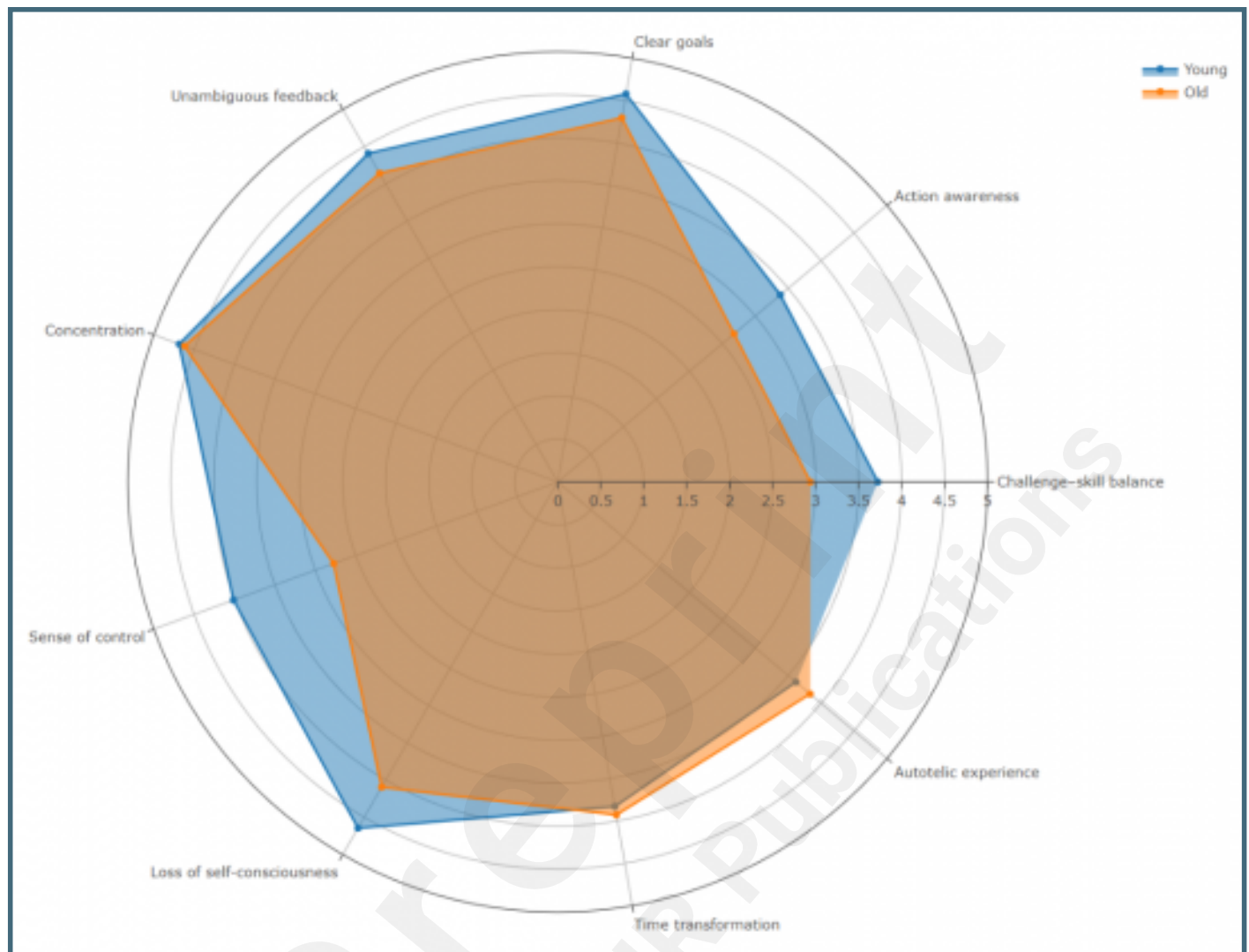
Supplementary Files

TOC/Feature image for homepages

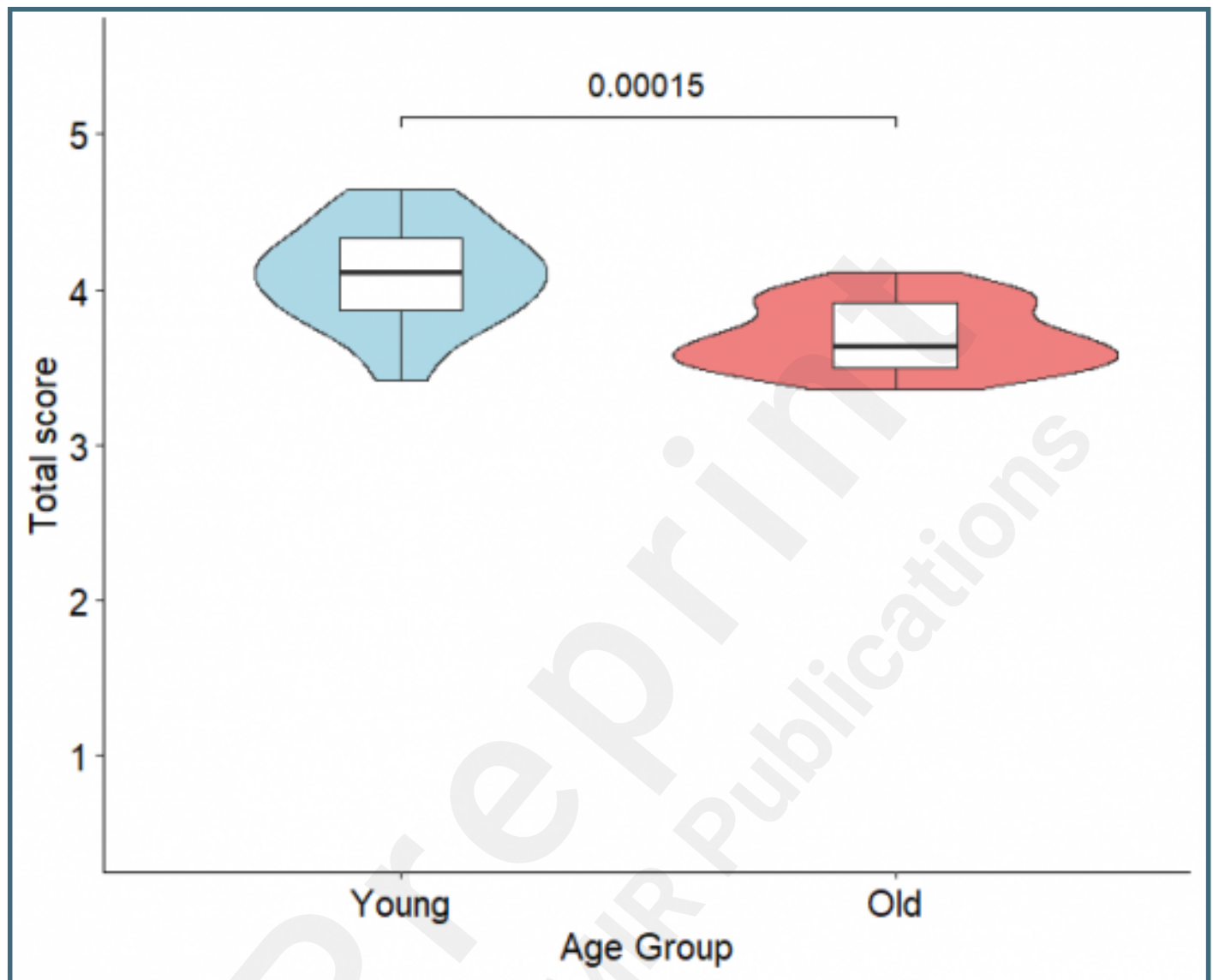
Schematic diagram of experimental procedure.



Radar chart of flow dimensions.



Violin plot of total flow.



Boxplot of flow dimensions.

