A Deconstruction of Expertise and Performance Through Arcade Games

Joshua Juvrud, Magnus Johansson, Gustaf Gredebäck, and Pär Nyström

***Abstract*—High levels of performance in video games may share the same underlying foundation for transfer with high levels of performance in musical instruments. The aim of this study was to examine the phenomenon of expertise by studying its underlying processes through eye movements during video game tasks. We compared three distinctly different groups ($N = 30$ adults) across a training and testing period: 1) people with experience in video games; 2) people with experience playing musical instruments, but no experience with video games; and 3) a control group with no experience with either computer games or musical instruments. Results showed that the musician group distinguished themselves through their pattern of eye movements, showing improvements in visual prediction and performance on par with experienced video game players. While the control group also showed overall improvement in performance and increased eye movements, only the group of musicians performed at the level of experienced video game players. Findings challenge previous assumptions that consider expertise as an isolated and task-specific ability that cannot be generalized to other areas and have significant implications for how we understand the development of expertise and general learning.**

***Index Terms*—Expertise, eye tracking, musicians, training, transfer, video games.**

I. Introduction

MANY individuals across countless domains and tasks perform at exceptional levels. For example, in a game of chess, Timur Gareyev played 48 opponents at one time blindfolded, keeping all of the positions in memory at one time, winning 35 of those matches. While this certainly demonstrates exceptional performance, ordinary people also demonstrate high levels of performance, or an expertise, in everyday contexts. Although more modest than Gareyev's feat, everyday expertise is crucial for a smooth and functional life. Yet, the underlying mechanisms behind developing an expertise are still not fully understood. While there are approaches to defining expert knowledge and its development [1], there is less work in exploring how expert abilities (e.g., particular abilities) become automated and to what extent these abilities generalize across tasks and domains.

A. Expertise

We define expertise as the "combination of knowledge, experience, and skills held by a person in a specific domain" [2]. Like chess masters and musicians, people who perform automated tasks, such as brewing tea [3], driving a car [4], or playing a video game [5], demonstrate expertise that is domain specific and is a result of many hours of rehearsed practice of particular foundational abilities.

From looking at studies on professional experts and expertise, we know that learning can occur both through structured training and the implementation of everyday tasks. This learning results in the automation of certain cognitive processes and the development of new abilities, leading to an increased degree of expertise within a specific domain [6], [7], [8]. While research has shown these abilities to be domain specific, it is clear that some common processes are central and are important across domains.

As certain cognitive processes are repeated, previously complex and demanding tasks become performed with minimal cognitive effort [6]. This process of automation means that an individual no longer needs to constantly generate new methods for processing and responding to input, freeing up cognitive resources for other tasks [8]. The freeing of cognitive resources is thought to be crucial for the development of expertise and necessary for mastering a task [6]. For instance, as an experienced musician automates the reading of sheet music, cognitive resources are free to be devoted to other tasks, such as holding significantly more notes in memory, focusing on tempo and dynamics, and reading further ahead to anticipate notes [9], [10].

Although the automation process has many advantages, it also poses some limitations. Achieving a high degree of automation requires training and repetition of a particular task, which results in task-specific skills that may have low generalization to other tasks [6], [11]. For example, a study of chess players showed that expert players were better than casual players at memorizing the position of chess pieces on a board. However, this only applied if the position of the pieces could be found in a real game set. If the positions were purely random, expert chess players' memory was no better than that of casual players [12]. Another study

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demonstrated that experts in the video game *Tetris* outperform novice players on tasks related to spatial rotation, but only if the task involved *Tetris*-like shapes. Both of these studies suggest that experts develop domain-specific abilities, such as pattern recognition, that are not easily generalized to other tasks [13], even tasks within the same domain.

There are some studies, however, that suggest that expertise in the domain of video games can generalize to other tasks. One study demonstrated that action video game playing altered a range of visual skills, including visual attention, that transferred to other tasks [14]. Transfer has also been observed in tasks that require high executive functioning and spatial cognitive abilities [6], [15], [16], [17]. This may be because certain kinds of video games are so mechanically complex and varied that players are constantly faced with new situations and degrees of randomness. Therefore, players cannot as easily rely on memorizing patterns or achieve a particularly high degree of automation [6].

B. Transfer

How is it that abilities trained in one domain can be generalized across multiple domains (commonly referred to as transfer)? Research focusing on simulations and skill transfer (e.g., serious games, games for learning, and game-based learning) indicates that transfer builds heavily on a high level of fidelity between simulation and actual skill domain for transfer to happen, even though other models for transfer can be present [18], [19]. Another way of looking at transfer is through the ecological approach [20], which claims that learning (or transfer) is not likely to occur when you are traversing the boundaries of an ecological niche, meaning that skills taught in one domain do not automatically carry over to a different context. Both the arguments would indicate that skills, knowledge, and performance are dependent on a very high level of concordance with the reality in which the specific skill is tested.

Other more recent findings, however, suggest an alternative explanation that indicates that "skills" or "knowledge" is not the underlying foundation of transfer; rather, fine motor control, bimanual dexterity, gaze control, and hand–eye coordination all have a positive impact on transfer from one activity to another [21]. Studies focusing on musicians have shown that music education has a positive impact on brain development in these areas [22] and that the enhancement of local processing abilities in musicians is not domain specific [23]. The skills developed in musicians, such as gaze control and hand–eye coordination, may, therefore, transfer to other domains and tasks.

High levels of performance in video games may share many of the same underlying foundation for transfer with high levels of performance in musical instruments. When learning to play video games, much like with musical instruments, abilities, such as timing, gaze control, visual prediction, and hand–eye coordination, may be important for developing expertise [24], [5]. Because of this foundation in underlying low-level motor processes, this cross-domain expertise may lead to a faster development of expertise in the other domain, possibly scaffolding the automation of processes in the new task. However, this has not been tested empirically previously.

C. Underlying Low-Level Motor Processes of Expertise

1) Gaze Control and Visual Prediction: One such ability is the gaze control of saccades and fixations for visual prediction: the capacity to use visual input to predict what will happen in the near future and subsequently plan appropriate actions [4], [25]. Humans make continuous sequences of sensory-motor decisions to satisfy current behavioral goals, and the role of vision is to provide the relevant information for making good decisions in order to achieve those goals. However, human body movements are slow and costly. The nervous system has built-in delays that slow the process from visual feedback to motor output [26]. Controlling one's gaze for visual prediction is, therefore, a necessary element of visual perception and is essential for coping in a constantly changing environment and for allowing actions with excellent precision despite our programmed delay [25], [27], [28].

2) Hand–Eye Coordination: It is through visual perception that, with training, an individual can perform precise and well-coordinated hand movements [29]. The process of responding to visual input accordingly through the coordinated control of eye and hand movements is referred to as hand–eye coordination. Hand–eye coordination is a central process not only in developing expertise across domains but also in the everyday interaction and manipulation of objects in our environment [30]. For example, when making a pot of tea or making a sandwich, individuals will fix their eyes already on the next step in the task chain to guide their subsequent hand [3]. The eyes are, therefore, not merely a passive response to current conditions in the environment but rather take an active lead in virtually every movement of the hand [31], [32], [33], even within virtual environments [34]. Studies have also shown how hand–eye coordination changes with increasing degrees of expertise, such as in musicians, which show changes in their eye-movement patterns and the number of notes a musician can process in advance [33], [35], [9], [10]. Other research has shown that musicians have faster reaction time compared to nonmusicians, linked to both vertical and horizontal discrimination, and that many years of musicianship lead to improved eye–hand coordination [36]. It is, therefore, an interesting question as to whether processes that may explain video game expertise, such as visual prediction and eye movements, can also be generalized to other types of expertise that consist of similar components.

D. Current Study

In this study, due to the visuomotor nature of both video gaming and playing musical instruments, we focus on underlying abilities of expertise related to eye movements. We developed two video games specifically for this study, named *Space Progress*, with inspiration from *Space Invaders*/*Galaga*, and *Brick Bandit*, with inspiration from *Brick Breaker*/*Arkanoid*. The rationale of using newly developed video games is that it offers an artificial environment that is entirely novel to all the participants, regardless of prior experience with specific games. Another advantage is that we can structure the game's parameters according to the specific variables of interest to the study. We could, therefore, tailor these games to answer questions related to the real-time development of expertise within the field of game studies and how underlying abilities generalize across tasks.

In this study, we compared three distinctly different groups: 1) people with experience in video games; 2) people with experience playing musical instruments, but no experience with video games; and 3) a control group with no experience with either computer games or musical instruments. We chose a group of musicians in order to relate expertise in visual prediction and hand–eye coordination with expertise transfer and game learning. If both musicians and gamers learn a new game equally fast, we can argue that there is a general underlying mechanism, but if gamers learn faster than musicians, there should be experience specific mechanisms involved.

II. Method

A. Participants

The total number of participants included 30 adults (female = 19, mean age = 20.5, and standard deviation (SD) = 0.93). Participants in the study were recruited from January 2019 through April 2019 using a stratified selection through advertising on various Internet forums and message boards in central Uppsala, Sweden. Participants were recruited from three distinct groups ($n = 10$ per group): video game players (people with experience in video games, but without experience of musical instrument; female = 5), musicians (people with experience connected to musical instruments, but without video game experience; female = 6), and a control group (people without experience of either video games or a musical instrument; female = 8). Participants who reported an interest in participating in the study completed inclusion questions via email. The variables used to assess a person's experience in video games and music were: play time per week within the last two months and the approximate amount of time the person has actively played (in years). In the selection, emphasis was placed on balancing the groups as much as possible. Video game players' prior experience with video games was on average 7.5 h per week (male = 8.6 and female = 6.4). The group of musicians played string instruments on average 3.96 h per week (male = 5.78 and female = 2.75). The control group had no experience with both video games (less than 1 h per week on average) and musical instruments (0 h per week on average) within the past ten years.

Adult participants provided informed consent and received 10€ gift voucher for participating. The study was conducted in accordance with the standards specified in the 1964 Declaration of Helsinki and approved by the local ethics committee.

B. Procedure

Participants visited the lab on three separate days within the same seven-day period. The first visit took 45 min and began with the researcher explaining the procedures and obtaining informed consent. The participant sat in front of a computer monitor with an eye tracker attached. The researcher first calibrated the eye tracker using a standard nine-point calibration procedure. Following calibration, the researcher explained the instructions for the first game, *Space Progress*, after which the participant played the game for a total of 6 min. Immediately following the *Space Progress* play session, the researcher explained the instructions for the second game, *Brick Bandit*, and the participant played the game for 30 min. These games are available for download for Windows online.[1] Instructions for both the games were verbally provided, as well as illustrated on a white board. During the second lab visit, calibration was followed by a *Brick Bandit* play session for 30 min. The third and final lab visits consisted of the calibration followed by a *Brick Bandit* play session for 30 min, immediately followed by *Space Progress* play session for 6 min. The whole intervention was, thus, an ABBBA sequence: 6 min *Space Progress*, 30 min *Brick Bandit*, 30 min *Brick Bandit*, 30 min *Brick Bandit*, and 6 min *Space Progress*. In this way, the first *Space Progress* served as a pretest, *Brick Bandit* as a training phase, and the final *Space Progress* served as a posttest of *Brick Bandit* expertise transfer.

C. Materials

1) Eye Tracking: Participants sat in a stationary armchair in a dimly lit room approximately 80 cm (46.05 visual degrees) in front of a large screen computer monitor (68 × 122 cm). Eye movements were recorded with a Tobii Nano eye tracker (60 Hz). Calibration was run using Tobii Lab Pro. Data from the eye tracker were recorded using Tobii Unity SDK for Desktop (version 3.0, Beta) from within the games and logged into a text file that contained synchronized gaze data and game state data.

2) Video Games: Both the games, *Space Progress* and *Brick Bandit*, were developed in Unity (version 2018.2.5f) by researcher Pär Nyström and were specifically developed for the present study. We have classified the games as classic arcade action games of semiretro character. Action game is an abstract video game category that often refers to the player requiring fast response times, visual prediction, and hand–eye coordination. A common game play mechanic in action games is for the player to pass various obstacles in order to clear different paths or levels. Within the action game category, there are various subcategories, such as fighting games, shooter games, and platform games. This particular category was chosen because it allows us to better study the underlying processes involved in the real-time development expertise, namely, visual prediction and hand–eye coordination.

a) Space Progress: Space Progress is a top-down perspective shooter, in which the player operates a spaceship (see Fig. 1). The goal of the game is to avoid collisions while also shooting down enemies. Participants controlled the game using keyboard arrow keys to both control movement and to shoot enemy ships. The participant was asked to use their dominant hand, unless otherwise preferred. The player pressed the up arrow key either to shoot or to move in the direction the ship was facing. The right and left arrow keys were used to change the direction of the ship. Thus, the up arrow key had different functions depending on the direction of the spaceship. The spaceship's shot exploded with a certain delay (2000 ms) in order to investigate the participants' ability to visually predict.

[1] [Online]. Available: https://osf.io/26vdw/

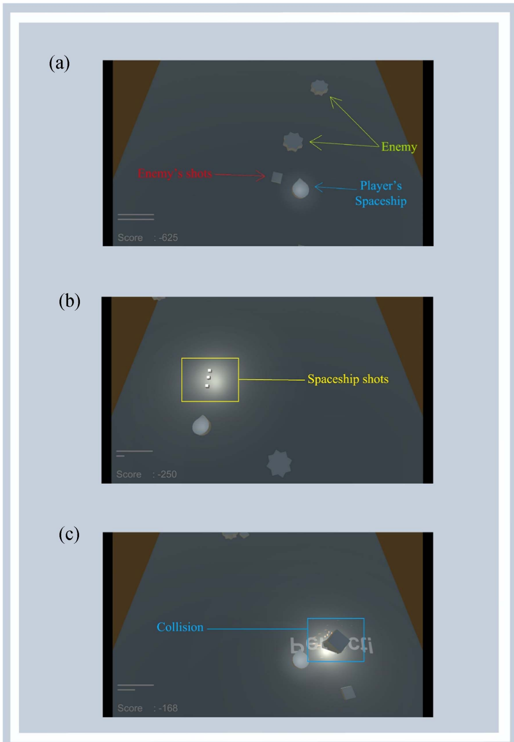

Fig. 1. Overview of *Space Progress*. (a) Game's main components: player spaceship, enemy shots, and enemies. (b) Player's spaceship firing shots. (c) Enemy shots or enemy spaceship hits the player's spaceship.

Fig. 2. Overview of *Brick Bandit*. The image highlights the game's main components: player's red tile, different colored tiles, and the white ball breaking a colored tile. The scale to the left of the game shows distances expressed in pixels. The scale was not shown to the study participants during testing.

If the fired shot exploded at an enemy position, this was counted as a hit, and the participant was rewarded with points. For each hit, the participant received 150–350 points (depending on the accuracy of the shot). For each collision with either enemy ships or enemy shots, the subject received a point deduction between 150 and 450 points (depending on the length of the collision). The participant played the game twice per testing, with each game taking 3 min regardless of performance.

b) Brick Bandit: In the game *Brick Bandit*, the player controls a red tile with the aim of bouncing a white ball off the red tile in order to hit different colored tiles (see Fig. 2). The player could move the red tile sideways and jump. The ball would bounce off the red tile, and when the ball bounced hit the different colored tiles, they were broken and rewarded the player with 15 points. If the player missed or dropped the ball from the red tile, they would lose 30 points. Therefore, the goal was to keep the ball in play as long as possible. When the player hit all the different colored tiles, the level was completed, and they would move on to the next one. The player controlled the game using a mini joystick (hand control). The participant was asked to use their dominant hand, unless otherwise preferred. The play time for each play session was 30 min, regardless of performance.

D. *Game Metrics*

We used the results from *Space Progress* as pre- and posttests for *Brick Bandit* expertise transfer. Results are, therefore, divided into pretest, test, and posttest. The pretest consisted of game round one and two of *Space Progress* (3 + 3 min), and the dependent variable analyzed was scored points during each round. Training consisted of game round one, two, and three of *Brick Bandit* (30 min lab visit 1 +30 min lab visit 2 +30 min lab visit 3). The mean distance between the gaze fixation and the red tile is a relative measure of the participants' visual prediction, as looking further up on the screen means that they are oriented toward future events in the game (different colored tiles). The total number of saccades provides information on a how participants moved their eyes across the screen, with more saccades demonstrating more eye movements. For each *Brick Bandit* game round, the dependent variables were, therefore, calculated as: 1) the mean distance between gaze fixations and the red tile; and 2) the total number of saccades. All eye-tracking data were analyzed at 60 Hz, with a change in values assessed every 180 s for each dependent variable (ten total data points per variable). This allowed an analysis of how eye movements changed over time throughout the session.

During posttest, we analyzed game rounds three and four of *Space Progress* (3 + 3 min), with the dependent variable again being total scored points during each round. We interpreted relative improvements across groups in *Space Progress* as due to the generalization of developed expertise in *Brick Bandit*, i.e., transfer.

III. Results

A. *Pretest*

We conducted a two-way (condition × game round) analysis of variance (ANOVA) to assess differences between the independent group scores during game round one and game round two of pretest. Observations we normally distributed and had equal variances. See Fig. 3(a) for pretest results. Results revealed a significant interaction between condition (musicians/gamers/controls) and game round (T1/T2), $F\ (21) = 5099$, $p < 0.001$, and $\eta p2 = 0.394$. There was also a significant main effect of game round ($F\ (11) = 5.099$, $p = 0.032$, and $\eta p2 = 0.159$). There was no main effect of condition ($F\ (12) = 3328$

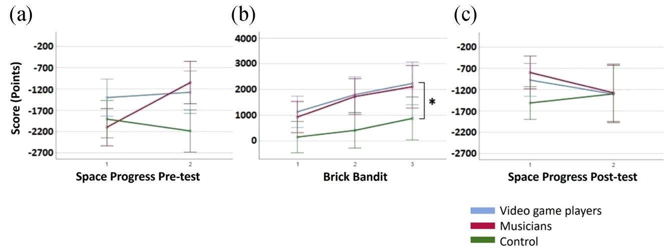

Fig. 3. Illustration of how the scores changed across game rounds for *Space Progress* and *Brick Bandit* for each group. (a) shows round one and round two mean scores for each group in *Space Progress* at the pretest. (b) shows round one, two, and three mean scores for each group in *Brick Bandit* at the test. (c) shows round one and two mean scores for each group in *Space Progress* at the posttest. ∗ = significance between groups ($p < 0.05$).

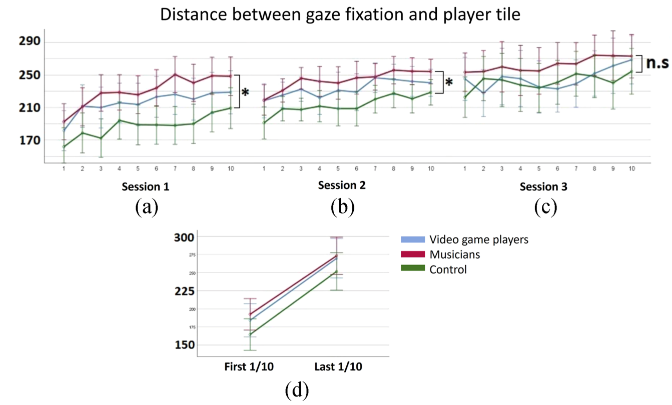

Fig. 4. For *Brick Bandit*, illustration of the change over time and across game rounds in the distance between gaze fixation and player's red tile for each group. (a) shows the distance between gaze fixation and the player's red tile during game round one. (b) shows the gaze fixation and the player's red tile during game round two. (c) shows the gaze fixation and the player's red tile during game round three. (d) compares the distance between gaze fixation and the red tile for the first tenth of round one with the last played tenth of round three. For distance, 100 pixels equal 6 visual degrees. ∗ = significance between groups ($p < 0.05$).

and $p = 0.051$). Note that all the values are negative, where a low value results in poorer results.

The results demonstrated that the musician group and the control group began at approximately the same score level during round one but differed over time. The video game player group, on the other hand, began with significantly higher scores and remained relatively the same at round two. At round two, the score of the musicians (M = –1047.5 and SD = 782.84) was higher than at round one (M = –2100.00 and SD = 633.44). The video game players' score at round one (M = –1402.50 and SD = 681.75) did not differ from game round two (M = –1277.00 and SD = 543.07) and remained relatively high. Similarly, scored points between round one (M = –1910.00 and SD = 712.80) and two (M = –2187.50 and SD = 929.48) did not differ in the control group and remained relatively low [see Fig. 3(a)].

1) Training:

a) Score analysis: We first analyzed scores from the independent groups using a two-way (game round × condition) ANOVA [see Fig. 3(b)]. Observations we normally distributed and had equal variances. Results revealed a main effect of condition ($F\,(12) = 4.283$, $p = 0.024$, and $\eta p2 = 0.241$). Both the musician group's scores (M = 928.50 and SD = 1036.80) and video game players' points (M = 1134.00 and SD = 1240.00) at game round one were significantly higher than the control groups' points (M = 150.00 and SD = 148.83) at game round one. Results also revealed a main effect of game round ($F\,(12) =$ 38885, $p < 0.001$, and $\eta p2 = 0.590$), demonstrating that all the groups showed improvement in scores from game round one to game round three, which we interpret as expertise development.

A Bonferroni post hoc test showed that the significant differences observed were between the video game player group and the control group ($p = 0.028$) but not between musicians and controls ($p = 0.075$) or video game players and musicians $p = 1.0$). There was no interaction effect between game round and condition ($F\,(22) = 1194$ and $p = 0.324$).

2) Gaze Analysis:

a) Gaze distance: We first analyzed the gaze distance (in pixels, where 100 pixels correspond to 6 angle degrees) between gaze fixations and the players' red tile using a three-way (condition × game round × time) ANOVA. Observations of the independent groups we normally distributed and had equal variances. Results revealed a significant main effect of condition ($F\,(12) = 4.643$, $p = 0.020$, and $\eta p2 = 0.279$). A Bonferroni post hoc test showed that there was a significant difference between the musician group and the control group ($p = 0.017$). The differences were significant for round one ($p = 0.017$) and round two ($p = 0.017$) but not for round three ($p = 0.774$) [see Fig. 4(a)–(c)]. Musicians and video game players did not significantly differ ($p = 0.591$) nor did video game players and the control group ($p = 0.379$).This means that initially, the gaze distance for video game players (M = 184.16 and SD = 30.14) was similar to the distance for musicians (M = 192.45 and SD = 40.69) but was significantly different from the control group (M = 164.56 and SD = 27.44). The video game players and control groups' distances differed on both session one and two (see Fig. 4(a) and (b)] but not during session three.

There was additionally a significant main effect of time ($F\,(19)$ = 28 986, $p < 0.001$, and $\eta p2 = 0.555$), as well as game round ($F\,(12)$ = 13 997, $p < 0.001$, and $\eta p2 = 0.368$), meaning that the distance between gaze fixation and the red tile increased for all the groups over time. However, at session three, the differences disappear as the mean distance of each group began to converge [see Fig. 4(c)].

We found no significant interaction effects for game round × condition ($F\,(2.2) = 0.614$ and $p = 0.654$) or condition × time ($F\,(2.9) = 0.873$ and $p = 0.612$).

To further examine how gaze distance changed throughout the test, we ran a two-way (time × condition) ANOVA [see Fig. 4(d)]. The dependent variable was the first tenth of session one, compared with the last tenth of session three. Observations we normally distributed and had equal variances. There was a significant main effect of time, meaning that all the group conditions increased their gaze distance across time ($F\,(11)$ = 75 103, $p < 0.001$, and $\eta p2 = 0.743$). There was no interaction between time and condition ($F\,(21) = 0.039$ and $p = 0.962$) and no main effect of condition ($F\,(12) = 2.526$ and $p = 0.099$).

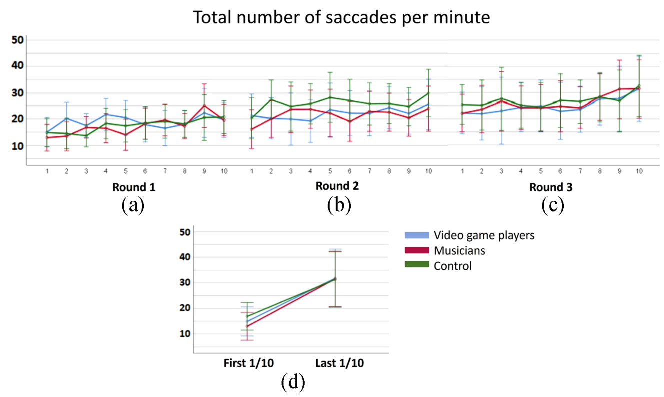

Fig. 5. For *Brick Bandit*, illustration of the change over time and across game rounds in the number of saccades for each group. (a) shows the number of saccades during game round one. (b) shows the number of saccades during game round two. (c) shows the number of saccades during game round three. (d) compares the number of saccades for the first tenth of round one with the last played tenth of round three.

Again, similar to game scores, we interpret this change over time as the development of expertise.

b) Number of saccades: We next analyzed the number of saccades using a three-way (condition $\times$ game round $\times$ time) ANOVA [see Fig. 5(a)–(d)]. Observations of independent groups we normally distributed and had equal variances. Results revealed a main effect of time ($F\,(19) = 8615$, $p < 0.001$, and $\eta p2 = 0.264$) and a main effect of game round ($F\,(12) = 12.34$, $p < 0.001$, and $\eta p2 = 0.340$), meaning that the number of saccades increased for all the groups across time and across all three rounds. There was no significant interaction between session and time ($F\,(29) = 1806$ and $p = 0.22$) or time and condition ($F\,(2.2) = 0.879$ and $p = 0.605$).

To further examine how saccades changed throughout the test, we ran a two-way (time $\times$ condition) ANOVA [see Fig. 5(d)]. The dependent variable was the first tenth of session one, compared with the last tenth of session three. There was a significant main effect of time, meaning that all the group conditions increased relatively equally in the total number of saccades across time ($F\,(11) = 26\,493$, $p < 0.001$, and $\eta p2 = 0.505$). There was no interaction between time and condition ($F\,(21) = 0.144$ and $p = 0.867$) and no main effect of condition ($F\,(12) = 0.088$ and $p = 0.916$).

B. Posttest

During the *Space Progress* posttest (round three and four), a two-way (condition $\times$ game round) ANOVA did not show any significant main effect of condition ($F\,(12) = 0.755$ and $p = 0.48$) or game round ($F\,(11) = 1.306$ and $p = 0.263$). There was also no significant interaction between time and condition ($F\,(22) = 1449$ and $p = 0.253$).

1) Comparison of Pre- and Posttests: To investigate whether *Brick Bandit* ability was transferred to *Space Progress*, we conducted a two-way (session $\times$ condition) ANOVA and analyzed the difference between the mean scores of the pretest with the mean scores of the posttest during *Space Progress* [see Fig. 3(a) and (c)]. Observations of independent groups we normally distributed and had equal variances. Results revealed a significant difference between the mean scores during pretest and mean scores for posttest ($F\,(11) = 9251$, $p = 0.005$, and $\eta p2 = 0.255$), with participants across all the groups showing increased scores during the posttest. There was no significant main effect for condition ($F\,(12) = 2682$ and $p = 0.087$) and no significant interaction between session and condition ($F\,(21) = 0.281$ and $p = 0.757$).

IV. Discussion

The overall aim of this study was to examine the phenomenon of expertise by studying its underlying processes through eye movements and overall game scores during video game tasks. The results from the current study showed that all the participants' performance increased in *Space Progress* after playing *Brick Bandit*, suggesting that increased expertise in one particular video game transferred to another video game. The effect sizes for the significant results were low to moderate (ranging from 0.241 to 0.555), likely due to lower sample sizes in the group comparisons. Nonetheless, the observed improvements occurred regardless of group—experienced video game players, experienced musicians, or control group. Therefore, the improvements captured in this study may be indicative of an expertise similar to that found in an everyday context, developing in real time.

One group, in particular, that distinguished themselves through their pattern of eye movements was of the musicians, who showed drastic improvements in visual prediction and performance on par with experienced video game players. While the control group also showed overall improvement in performance and increased eye movements, only the group of musicians performed at the level of experienced video game players already by the second session. This challenges previous assumptions that considered expertise as an isolated and task-specific ability that cannot be generalized to other areas [6]. It appears that musicians possess an underlying ability that is important for success at video games, an ability that has been gained and transferred from their own musical experiences.

A reasonable explanation for video game players and musicians performing similarly could be the development of hand–eye coordination skills. This is suggested to be an important ability when both playing musical instruments and video arcade games. When learning to play video games, well-developed hand–eye coordination may perhaps be even more important than experience alone. Another explanation is that a combination of fine motor control, bimanual dexterity, and good hand–eye coordination can have a positive impact on learning from one activity to another. This is consistent with the previous finding [21], which has shown high levels of abilities playing the piano had a positive effect on training surgical procedures.

All the current study's musicians practiced string instruments, including the piano, cello, violin, and guitar, which place high demands on the practitioner's dexterity. For a musician, to be able to identify notes on a sheet of music and then translate them to finger movements on keys or strings and execute them correctly with tempo is not completely different from identifying objects on a screen and then reacting with a correct and precise response on a keyboard. It is possible that the group of musicians learned faster to automate the control of the spaceship, maybe thanks to well-developed eye–hand coordination, which freed up cognitive resources for other aspects of the game. Indeed, previous research has also shown that musicians generally have improved reaction times compared to controls [36], [37]. Together, skilled hand–eye coordination, finger motorization, and reaction time may provide a basis for good performance in certain video games.

Another possible explanation could be a general increase in the automation of eye-related movements for encoding information. Both novice game players and musicians may require more slow and conscious visual behavior in order to process information related to performance. As these visual processes become automated, more cognitive resources are free to be used for more complex cognitive functions, such as prediction. The current study cannot disentangle the visual and cognitive processes involved in encoding information in a game from the resulting motor responses needed to play the game, but the results here suggest that they are indeed related to some capacity. Importantly, the results also show that these underlying processes transfer across the domain of video games and musicians independent of shared experience in those domains.

V. Conclusion

The phenomenon of developing expertise seems to be considerably broader than what previous work has suggested. The relationship between experience and performance can be explained by more than just the number of game hours and task specificity [13], [19]. Based on the present study, fine motor control, visual and motor coordination is an ability that is important in the development of expertise and training of a new task. Although one should not write off the importance of experience and training, it seems that some underlying generalizing abilities may facilitate the learning of brand-new ones across different tasks.

It is likely that visual prediction and hand–eye coordination are also relevant for other tasks with similar characteristics to musical instruments and video games and would similarly generalize to such tasks. The current study did not capture complete mastery of a task. Further research should continue to examine the development of expertise from novice up until complete mastery in order to better understand professionals within certain domains, such as the concert pianist and professional esport competitors. Another limitation of this study, also found in similar studies [21], is the focus on how musicians can pick up skills not directly connected to their musical skills in a one-way direction. In order to say more about about the acquisition of skills and brain development, people who identify as highly skilled gamers should be tested in other domains, such as music, to see if the reversed relation exists.

The current study represents only a glimpse into the development expertise as it relates to hand–eye coordination. We see promise for future studies that expand the scope and address key limitations. First, we see many opportunities for additional designs and analyses, such as fixation patterns and gaze latency. A larger sample size would also strengthen these findings. In addition, it would be beneficial to broaden the scope of the type of games examined, specifically games with a steeper learning curve or even more advanced cognitive strategies (e.g., *Tetris*). This could clarify whether the overall performance in the posttest was a result of reaching a skill gap or motivation. Finally, involving key stakeholders, such as game designers, could help support intentionally designing for training expertise.

For researchers and educators, these findings have significant implications for how we understand the development of expertise and general learning. Learning programs can be used that utilize individual skill sets and already-trained processes, such as visual processing and hand–eye coordination, in order to facilitate learning in other areas. For game designers and game researchers, these findings are in line with the idea that video games may further develop certain visual and cognitive skills, as previously suggested [38]. For game designers, this may also influence design principles within a game, providing evidence for a structured design in which game mechanics can build upon one another, and learned skills can transfer from one context to the next. For instance, games designed for learning (also referred to as serious games) can utilize the training of underlying visual and cognitive processes to facilitate the development of expertise.

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