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Original Article

Cognitive Differences Between Multilinguals and Monolinguals in Terms of Motor Skills

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Abstract

Objectives: Multilingualism has been proposed to enhance executive control and domain-specific cognitive and motor processes. This study examined whether multilingual adults show advantages over monolinguals in visuospatial working memory, sensorimotor speed, and short-term motor learning during an exergame program.

Methods: In a between-groups, repeated-measures design, forty healthy adults aged 18–50 years (20 multilingual, 20 monolingual) completed neuropsychological tests (Fitts's law task, Corsi Block Span, Stroop, Wisconsin Card Sorting Test (WCST), cued task switching). They played Kinect-based exergames on Days 1, 3, 5, and 7. Language proficiency (LexTALE), prior gaming frequency, and health measures (Pittsburgh Sleep Quality Index, beck depression ınventory, Beck Anxiety Inventory, mini-mental state examination) were recorded. Group comparisons used independent t-tests or Mann-Whitney U tests as appropriate, and repeated-measures analysis of variance assessed learning trajectories across sessions.

Results: Multilinguals showed significantly faster response times in the Fitts's law task ($p<0.001$) and higher spans on the Corsi Block test ($p=0.003$). No reliable group differences were observed for Stroop, WCST, or task-switching performance (all $p>0.05$). Exergame performance improved across sessions in both groups, with a significant group × day interaction indicating steeper learning trajectories among multilinguals ($p<0.01$).

Conclusion: Multilingualism was associated with enhanced visuospatial working memory and sensorimotor speed and greater short-term gains in motor learning during exergame practice. These findings support the view that multilingual experience may strengthen visuomotor integration networks through experience-dependent plasticity. Replication in larger, longitudinal samples is warranted to clarify mechanisms and inform neurorehabilitation applications.

Keywords: Exergames, Kinect, monolingual, motor learning, multilingual, Xbox.

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Language is one of the most complex human abilities, shaping communication, cognitive processes, and brain organization. Advances in neuroimaging and analytical methods have revealed that learning and using language are associated with structural and functional plasticity in the brain.[1,2]

Bilingualism and multilingualism, in particular, have been a significant focus of cognitive neuroscience research. Conforming in multiple languages requires continuous monitoring, selection, and switching between linguistic codes, which can enhance cognitive flexibility and attentional control. Numerous studies have shown that bilinguals often recruit overlapping but dynamically adapted neural circuits, with language experience modulating universal linguistic pathways through individual practice.[3–7]

Despite this, the so-called "bilingual advantage" remains debated. Some meta-analyses and large-scale studies have reported benefits in executive control, working

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memory, and attentional shifting, while others have failed to find reliable effects.[8–14] This inconsistency suggests that the cognitive effects of multilingualism may be domain-specific rather than global, emerging more strongly in certain tasks or under specific environmental and methodological conditions.

One underexplored area is the relationship between multilingualism and sensorimotor processing. Language switching requires rapid and flexible coordination, potentially engaging posterior perceptual–motor systems alongside frontal executive networks.[3–5,7,15] This raises the possibility that multilingual adults may show enhanced visuospatial working memory, faster motor responses, and improved motor learning compared to monolinguals.

At the same time, emerging evidence highlights the role of digital exergames – interactive video games requiring physical movement – in promoting cognitive and motor functions. Exergaming has been linked to improved attention, visuospatial abilities, and motor coordination across clinical and non-clinical groups.[16–20] However, no study has directly investigated whether multilingual experience influences short-term motor learning during exergame training.

The present study addresses this gap by examining whether multilingual adults outperform monolinguals in (a) neuropsychological measures of visuospatial working memory, sensorimotor speed, and executive control, and (b) learning trajectories across 1 week of Kinect-based exergame practice. We hypothesized that multilinguals would demonstrate faster responses on the Fitts' law task and greater visuospatial span on the Corsi block test. We further expected steeper improvements in exergame performance across sessions, while analyses of Stroop, Wisconsin Card Sorting, and cued task switching were treated as exploratory.

Materials and Methods

Participants

These between-groups, repeated-measures study was conducted at Bahçeşehir University, Graduate School of Health Sciences, Department of Neuroscience. The study complied with the Declaration of Helsinki and was approved by the Bahçeşehir University Ethics Committee on 15/01/2020.

Forty healthy adults (20 multilingual; 20 monolingual; age range 18–50 years; balanced for sex) were recruited according to predefined inclusion and exclusion criteria (Table 1). Multilingual participants were Turkish speakers who also spoke English and/or French. Exclusion criteria included prior diagnosis of neurological or psychiatric disorders, regular use of psychoactive medication, and gaming experience of more than four sessions per week in the past 6 months. All participants provided written informed consent in their native language (Turkish for monolinguals, English for multilinguals).

Health and Screening Measures

To ensure general health comparability, participants completed the beck depression inventory (BDI), Beck Anxiety Inventory (BAI), Pittsburgh Sleep Quality Index (PSQI), and Mini-Mental State Examination (MMSE). Only individuals with scores within the accepted thresholds (Table 1) were included.

Neuropsychological Testing

On Day 1, participants completed the LexTALE language proficiency test (French version: Brysbaert, 2013).[21] A minimum cut-off score of 50% was required for inclusion in the multilingual group.

Participants then underwent standardized neuropsychological tests assessing attention, visuospatial working memory, executive function, and sensorimotor speed. These included:

Table 1. Inclusion and exclusion criteria

	Inclusion criteria	Exclusion criteria
BDI score	1–16± medication	>16±medication
BAI score	0–25± medication	>25±medication
Age	18–50 years	<18 or >50 years
MMSE score	30	<30
Gender	Male/female	-
Language	Turkish	University Majors in English, French, Turkish
Level of education	Undergraduate and above	
Gaming experience	<4 times per week	≥4 times per week

BDI: Beck depression ınventory, BAI: Beck anxiety inventory, MMSE: Mini-mental state examination

- Fitts's law task (reaction time),
- Corsi block-tapping test (visuospatial span),
- Stroop task,
- Wisconsin card sorting test (WCST),
- Cued task-switching test.

All tasks were administered via PsyToolki.[22,23]

Exergame Intervention

Participants played Kinect Adventures (Microsoft Xbox 360 Kinect system) in four sessions (Day 1, 3, 5, and 7). Each session lasted 30 min and included three exergames: Reflex Ridge, Rally Ball (Peek-a-Boo), and 20,000 Leaks (Go with the Flow). The system automatically recorded performance scores and tabulated them for analysis.

Primary and Secondary Outcomes

The primary outcomes were selected to capture core visuomotor and visuospatial abilities most likely to differentiate multilinguals from monolinguals based on prior evidence of bilingual advantage in sensorimotor and working memory domains.

1. Sensorimotor response speed was quantified using the mean movement time in the Fitts' law task, which indexes visuomotor coordination and speed-accuracy trade-off efficiency.
2. Visuospatial working memory was assessed via the Corsi Block-Tapping test, using the highest correctly recalled sequence length (Corsi span) as the dependent variable.
3. Exergame learning trajectories were operationalized as total Kinect performance scores across four sessions (Days 1, 3, 5, and 7), reflecting short-term motor learning and adaptation.

These measures were defined as primary outcomes because they directly represent sensorimotor integration and visuospatial processing, functions previously linked to bilingual language control and experience-dependent plasticity.

Secondary exploratory outcomes included measures primarily reflecting executive control: Stroop interference scores (inhibitory control), WCST categories completed and perseverative errors (set-shifting), and cued task-switching cost, representing cognitive flexibility. These outcomes were examined to determine whether multilingual advantages extend beyond the visuomotor domain to broader executive processes.

Statistical Analysis

Baseline demographic and health variables (e.g., age, sex, BDI, BAI, PSQI, MMSE) were compared between groups using independent-samples t-tests or chi-square (χ^2) tests, as appropriate. Between-group differences in neuropsychological task performance and exergame scores were initially evaluated using independent-samples t-tests. Normality assumptions were assessed using the Shapiro–Wilk test, and homogeneity of variances was examined with Levene's test. When statistical assumptions were violated, the non-parametric Mann–Whitney U test was applied.

To examine performance changes across exergame sessions, a repeated-measures analysis of variance (ANOVA) was conducted with Group (multilingual vs. monolingual) as the between-subjects factor and Time (Day 1, Day 3, Day 5, Day 7) as the within-subjects factor. Effect sizes (Cohen's d and partial η^2) and 95% confidence intervals were reported where applicable. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $p<0.05$.

Results

Demographics

The demographic characteristics of participants are shown in Table 2. Of the 40 participants, 23 (57.5%) were female, and 17 (42.5%) were male. The multilingual group included 13 females and seven males, while the monolingual group comprised 10 females and 10 males. The mean age across the total sample was 27.3±3.1 years, with no statistically significant difference between the groups ($p>0.05$). Thus, the two groups were comparable regarding basic demographic variables, minimizing potential confounding effects of age and gender.

General Health Results

Table 2 also presents the results of general health screening measures. The mean PSQI score was 7.0±3.6, indicating poor sleep quality overall. Multilingual participants demonstrated slightly lower PSQI values than monolinguals, suggesting a trend toward better subjective sleep quality, though differences were not statistically significant ($p>0.05$). Mean BDI and BAI scores were 7.6 and 8.4, respectively, within the non-clinical range. While multilinguals had somewhat lower depression scores than monolinguals, anxiety scores were comparable across groups.

Language Test Results

LexTALE scores are summarized in Table 3. Among multilinguals, 80% reported bilingual proficiency and 20% trilingual proficiency. The average English LexTALE score was 68.7, and the average French score was 74.4, comfortably above the 50% inclusion threshold.

Table 2. Health assessment group differences between monolingual and multilingual

Grouping (Monolingual=A, Multilingual=B)	Mean
Gender distribution	
A (male)	10±0
(Female)	10±0
B (male)	7±0
(Female)	13±0
Age	
A	27.25±3.076
B	27.35±3.216
Pittsburgh sleep quality index	
A	8.80±3.592
B	5.35±2.796
Beck's depression score	
A	8.75±3.291
B	6.35±4.626
Beck's anxiety score	
A	8.60±3.747
B	8.10±7.405

Neuropsychological Test Results

- Fitts's law task: Multilinguals exhibited significantly faster response times than monolinguals (Table 4). Group differences were confirmed by independent t-tests ($p<0.001$, Table 5).
- Corsi block-tapping test: Multilinguals achieved higher mean span scores (M=5.45) compared to monolinguals ($p<0.05$).

Table 3. Language score mean distribution between English and French speakers

Lextale exam score distribution		
Total No. of participants (n=20)	**LexTale English score (n=20)**	**LexTale French score (n=4)**
Mean	68.7065	74.4875
Median	73.1250	74.6750
Standard deviation	13.08421	4.21137

- Stroop test: No significant group differences ($p>0.05$, Table 5).
- WCST: Multilinguals made fewer errors, but group differences were insignificant ($p>0.05$, Table 5).
- Cued task-switching: No significant group differences ($p>0.05$, Table 5).

Exergame Scores

Table 6 summarize performance across four exergaming sessions. Both groups improved over time. Multilinguals consistently achieved higher scores, indicating steeper learning trajectories.

- Reflex ridge: Significant group differences ($p<0.05$; Mann-Whitney $p<0.001$ on some days).
- Rally ball: Multilinguals scored higher each session; Day 3 required Mann-Whitney ($p<0.05$).
- 20,000 leaks: Multilinguals significantly outperformed monolinguals across all sessions ($p<0.05$).

Table 4. Neuropsychological tests mean frequency distribution

Neuropsychological tests mean frequency distribution (mean±standard deviation)		
	Monolinguals	**Multilinguals**
Fitt's mean response time	883.55±164.6	676.34±106.0
Corsi block test mean	4.60±0.754	5.45±0.945
Stroop test speed in correct incongruent	871.500±209.48	894.500±143.49
Speed in correct incongruent	981.25±241.40	1008.60±129.55
Stroop effect	109.75±126.49	114.35±114.64
Wisconsin card sorting test preservation	8.5000±2.259	7.9500±3.817
Non-preservation	4.1000±2.751	3.5500±2.187
Task switching cued avg. RT in all correct	720.05±211.41	618.45±105.77
Avg. RT in task repeat	682.60±192.28	586.30±86.378
Avg. RT in task switch	723.30±281.09	651.00±130.89
Task switch cost	68.400±81.602	64.700±93.392
Avg. RT in task congruent	724.65±227.84	609.60±93.091
Avg. RT in task incongruent	722.90±201.92	631.75±114.92
Task interference	16.1500±112.45	22.150±56.727

Table 5. Neuropsychological tests sample t-test distribution

Neuropsychological tests sample t-test distribution						
Fitt's mean response time	**Levene's test for equality of variances**			**t-test for equality of means**		
		F	**Significant**	**t**	**df**	**Significant (2 tailed)**
	EVA	0.948	0.336	4.731	38	0
	EVNA			4.731	32.446	0
Corsi block test mean	EVA	0.346	0.56	-3.145	38	0.003
	EVNA			-3.145	36.221	0.003
Stroop test						
Speed in correct congruent	EVA	5.256	0.028	-0.405	38	0.688
	EVNA			-0.405	33.613	0.688
Speed in correct incongruent	EVA	9.456	0.004	-0.446	38	0.658
	EVNA			-0.446	29.106	0.659
Stroop effect	EVA	0.124	0.727	-0.12	38	0.905
	EVNA			-0.12	37.638	0.905
Wisconsin card sorting test						
Preservation	EVA	0.885	0.353	0.554	38	0.583
	EVNA			0.554	30.855	0.583
Non-preservation	EVA	1.124	0.296	0.7	38	0.488
	EVNA			0.7	36.167	0.489
Task switching cued						
Task switch cost	EVA	0.567	0.456	0.133	38	0.895
	EVNA			0.133	37.328	0.895
Task interference	EVA	5.52	0.024	-0.213	38	0.832
	EVNA			-0.213	28.082	0.833

EVA: Equal variances assumed; EVNA: Equal variances not assumed.

Discussion

This study investigated whether multilingualism is associated with advantages in cognitive performance and short-term motor learning. The main findings were that multilingual participants outperformed monolinguals on the Fitts's law task and the Corsi Block-Tapping test, indicating enhanced visuomotor speed and visuospatial working memory. By contrast, no significant group differences were observed for Stroop, WCST, or cued task-switching measures. In the exergame intervention, multilinguals consistently achieved higher scores and steeper improvements across sessions than monolinguals.

These results contribute to the ongoing debate regarding the "bilingual advantage." While some studies have reported cognitive benefits of bilingualism, others have found inconsistent or null effects. Recent meta-analyses emphasize that such advantages are not global but rather domain – and context-specific.[8–14,24–26] Our findings align with this perspective: multilingualism was not associated with broad enhancements in executive control but was linked to advantages in visuospatial and motor learning domains.

The superior performance of multilinguals in the Fitts's law and Corsi tasks may reflect experience-dependent plasticity in perceptual-motor networks. Frequent switching between languages engages executive and posterior perceptual-motor systems, potentially reinforcing visuospatial working memory and rapid motor responses.[3–7,15,27] This interpretation is supported by previous work showing the benefits of visuospatial memory in bilinguals.[28] The exergame findings extend this interpretation, as multilinguals demonstrated steeper learning trajectories in tasks requiring dynamic visuomotor coordination, consistent with evidence that gaming interventions can support motor learning.[16–20,29]

An important implication of these results is that multilingual experience may act as a form of "cognitive-motor training." Language switching requires rapid inhibition and activation of competing representations, which recruit prefrontal

Table 6. Xbox Kinect games sample t-test distribution

XBOX kinetic games sample t-test distribution										
	Day 1		Day 3		Day 5		Day 7		Total scores	
	EVA*	EVNA**	EVA	EVNA	EVA	EVNA	EVA	EVNA	EVA	EVNA
Reflex ridge										
Levene's test for equality of variance										
F	2.068		2.154		10.732		6.041		6.53	
Sig.	0.159		0.15		0.002		0.019		0.15	
t-test for equality of means										
t	-7.063	-7.063	-8.098	-8.098	-8.655	-8.66	-8.458	-8.458	-8.398	-8.398
df.	38	35.972	38	34.94	38	29.3	38	32.532	38	31.835
Sig. (2 tailed)	0	0	0	0	0	0	0	0	0	0
Mann-Whitney U Results[a]										
Mann-Whitney U	22.5		15		11		11		11	
Wilcoxon W	232.5		225		221		221		221	
Z	−4.802		−5.004		−5.113		−5.112		−5.113	
Asymp. Sig. (2-tailed)	0		0		0		0		0	
Exact Sig. [2 (1-tailed Sig.)]	000b		000b		000b		000b		000b	
Rally Ball										
Levene's test for equality of variance										
F	2.16		4.647		1.962		0.756		1.731	
Sig.	0.15		0.038		0.169		0.39		0.196	
t-test for equality of means										
t	-4.83	-4.83	-5.169	-5.169	-6.156	-6.16	-6.073	-6.073	-6.069	-6.069
df.	38	36.013	38	30.94	38	33.3	38	33.5	38	34.987
Sig. (2 tailed)	0	0	0	0	0	0	0	0	0	0
Mann-Whitney U Results[a]										
Mann-Whitney U	62		45		.5		29		34	
Wilcoxon W	272		255		240.5		239		244	
Z	-3.733		-4.194		-4.585		-4.626		-4.491	
Asymp. Sig. (2-tailed)	0		0		0		0		0	
Exact Sig. [2 (1-tailed Sig.)]	000b		000b		000b		000b		000b	
20,000 Leaks										
Levene's test for equality of variance										
F	7.981		0.029		1.046		0.001		2.342	
Sig.	0.007		0.866		0.313		0.971		0.134	
t-test for equality of means										
t	-8.103	-8.103	-6.981	-6.981	-7.336	-7.34	-7.382	-7.382	-8.179	-8.179
df.	38	30.705	38	37.96	38	37.6	38	37.983	38	35.618
Sig. (2 tailed)	0	0	0	0	0	0	0	0	0	0

[a]: Grouping variable: Multilingual, [b]: Not corrected for ties. *: EVA: Equal variances assumed, **: EVNA: Equal variances not assumed.

regions and premotor and subcortical structures such as the basal ganglia.[6,15] Over time, this repeated engagement may strengthen critical pathways for sensorimotor coordination. Furthermore, neuroimaging evidence suggests that bilingual experience recruits the cerebellum and motor cortices during linguistic and non-linguistic tasks, providing a mechanistic link between multilingual practice and enhanced motor learning. The overlap between language and sensorimotor circuits supports the idea that managing multiple languages could generalize

beyond executive control to motor skill acquisition. In line with this interpretation, studies highlight the cerebellum's dual role in speech-language processing and fine motor control,[30] and electrophysiological evidence indicates that sensorimotor circuits underpin aspects of language perception and production.[31] From this perspective, multilingualism may confer cognitive reserve and enhance motor adaptability through shared neural substrates.

Our results showed no reliable group differences for Stroop, WCST, and task-switching. This is consistent with studies reporting limited or absent multilingual advantages in inhibition and cognitive flexibility.[13,14] Some authors argue that such tasks rely more heavily on domain-general executive control, where effects of multilingualism may be less pronounced or moderated by other factors such as age of acquisition, daily language use, and sociocultural context.[32]

The integration of exergames in this study adds a novel dimension. Prior work has shown that exergaming can enhance visuospatial skills, attention, and motor learning.[16–20] Our data extend these findings by showing that multilingual participants may benefit more strongly from repeated exergame training. The convergence of advantages observed in neuropsychological and exergame tasks suggests that multilingualism may confer specific benefits when tasks place high demands on visuomotor integration.

At the same time, our findings must be interpreted cautiously. The sample size was modest, limiting power to detect more minor effects and precluding multivariate analyses to control for confounders such as sleep quality and mood. The duration of the intervention was short (1 week), and participants varied in their age of acquisition and proficiency levels in the second and third languages. Sociocultural and educational factors may also contribute to cognitive and motor differences. These limitations underscore the need for larger, longitudinal studies with careful stratification of language background variables.

Despite these caveats, the current study highlights potential implications for neurorehabilitation. Exergame-based training combined with the cognitive reserve associated with multilingualism could represent a promising avenue for enhancing rehabilitation outcomes in conditions involving motor deficits, such as Parkinson's disease or cerebral palsy. Future research should explore whether language experience moderates the efficacy of such interventions and whether incorporating multilingual training elements into rehabilitation protocols could further enhance outcomes.

Conclusion

The present study suggests that multilingual adults show measurable advantages in visuomotor speed, visuospatial working memory, and short-term motor learning compared to monolinguals. These effects were consistently observed in the Fitts' law and Corsi tasks and in exergame performance across repeated sessions. By contrast, no reliable group differences were found for Stroop, WCST, or task-switching, supporting recent evidence that multilingual advantages are domain-specific rather than global.[8–14,24–26]

Taken together, these findings highlight that multilingualism may contribute to cognitive reserve and enhanced motor adaptability. The observed link between language experience and sensorimotor efficiency suggests that multilingualism can act as a form of ongoing "cognitive-motor training." This perspective emphasizes the overlap between language networks and motor circuits, including prefrontal, cerebellar, and sensorimotor pathways.[15,30,31]

Although preliminary, our results may carry implications for clinical and translational neuroscience. Exergame-based interventions combined with the cognitive enrichment of multilingualism could support rehabilitation strategies for disorders involving motor and cognitive decline, such as Parkinson's disease, stroke, or mild cognitive impairment. Future work should examine whether multilingual experience moderates the efficacy of such programs and whether integrating language-based enrichment into rehabilitation protocols can further optimize outcomes.

Disclosures

Ethics Committee Approval: The study was approved by the Bahçeşehir University Ethics Committee (no: 20021704-604.01.01, date: 15/01/2020).

Informed Consent: Informed consent was obtained from all participants.

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