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Evaluations of the Data from the Spatial Thinking Platform RIF Show a Clear Trend: Girls and Boys Have Equally Good Spatial Thinking Skills

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Abstract. Since 2019, the online platform RIF has collected anonymous results from more than 2.5 million individual tasks completed by students from 33 countries around the world. This large amount of data allows analyses, various evaluations, and interpretations of users' spatial thinking skills. Since the majority of students participating in RIF are between the ages of 12 and 27, the results of this age group in particular were examined with regard to age- and gender-specific differences and performance in the different areas of spatial thinking. The results of the analyses show clear trends: (1) Girls and boys have (cum grano salis) equally good spatial thinking skills. (2) The analysis of all nine domains of spatial thinking included in RIF shows that boys have an advantage only in the domain of mental rotation. (3) The largest difference between boys and girls in the area of mental rotation is noticeable at the age of 15 to 17. (4) The gender difference in mental rotation decreases considerably with increasing age of students. (5) With increasing age, the average probability of solving the tasks correctly increases for all students in all domains of spatial thinking.

Key Words: spatial thinking, spatial ability, education, geometry
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1 Introduction

1.1 Spatial Ability

Scientists have been intensively researching the construct of spatial ability for about 150 years. Starting with Sir Francis Galton, who wrote one of the first verifiable publications on spatial

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ability in 1879 [7], to a variety of scientists from different disciplines on all continents (e.g., Sherly Sorby (USA), Tom Lowrie (Australia) and Jeff Buckley (Ireland)). A wide variety of models of spatial ability have been formulated [5, 15, 16, 22, 31, 40] based on diverse models of intelligence [12, 39], and manifold studies of trainability [10, 27] and strategy use [19, 38] have been conducted. The structure of current models of spatial thinking is mostly *minimalist* [31] or *maximalist* [2], or they are conceptualized as *cross-domain models* [22].

In general, the ability to think spatially is one of the most fundamental cognitive abilities of humans. It enables us to move in our environment, to aim at targets, to plan routes, to estimate distances, and to recognize the position of spatial objects in relation to each other. Spatial thinking includes the ability to imagine spatial objects and to rotate, mirror, and move them purely by the power of our imagination, to imagine the position of several objects in relation to each other in space, and to imagine intersections of objects [23]. In addition, the ability to think spatially includes the ability to mentally take other perspectives.

More than ever, the ability to think spatially is needed in our modern technology-based world. An analysis of the major social changes since the turn of the millennium shows that our world is continuously becoming more digital, data-based, and visual [27]. In almost all areas of our private and professional everyday life, we are increasingly confronted with visual information and challenges. We must recognize them, interpret them correctly, and make appropriate decisions based on that visual information (e.g., navigation devices). Within the next few years, we will encounter numerous new visual developments in our private and professional everyday lives that will require even better and more sophisticated spatial thinking skills than have been necessary before.

Besides being necessary for fulfilling everyday tasks, spatial ability is considered a strong predictor for success in STEM (short for Science, Technology, Engineering, Mathematics) [2, 43]. Additionally, having high spatial skills is linked to higher probability of choosing and being successful in a STEM career [43]. Based on these facts, a well-developed ability to think spatially can be recognized as one of THE key qualifications for a promising career in the STEM areas.

With regard to the efficient trainability of spatial thinking skills, there is much evidence to suggest that multifaceted training that incorporates a wide variety of diverse task types [26] is the most useful way of improving this area of intelligence.

Several studies from a lot of researchers from all over the world have pointed out gender differences in spatial thinking skills [3, 4, 9, 11, 17, 28, 29, 32, 37]. Regarding these gender differences, meta-analyses by Voyer, Voyer, and Bryden [42], and Linn and Petersen [15] have shown interesting effects between at least three subdomains of spatial ability: Whereas gender differences have declined over the years for visualization and spatial orientation [8], they are still regularly found for mental rotation [34]. One of the questions of general interest is whether these differences are biologically or socially determined.

However, other studies show that biological influences are not completely negligible. Hormonal level [36], hemisphericity [25], timing of puberty [30], and handedness [1, 6] have been shown to be related to spatial thinking skills [34]. One important aspect in this discussion is whether it is possible to make gender differences in spatial ability disappear by training female subjects properly: if this is possible, and especially if the training effect transfers to other fields of performance within spatial ability, socio-educational theories would be strongly supported [8]. Closely connected to biological influences is possibly the fact, that in many studies the gender differences occur at the age of puberty [29, 41]. Much research has investigated effort to find out if hormonal differences especially at the age of puberty can explain the gender differences in spatial ability at this age group [24]. The results are controversial and to date there are no clear and consistent findings as to whether hormonal differences during puberty are the cause of gender differences. It still is also not clear when the differences occur and if the gender differences – mainly in the domain of mental rotation – stay continuously the same during all age groups beginning from puberty or if they change during lifetime.

1.2 The Online Platform RIF

"As others have pointed out, the crux of cognitive training is not to improve performance on a particular task, but to improve performance of a latent ability that is expressed in multiple tasks." [26]. This statement of Mix and colleagues was one of the most important pillars for the scientific foundation of the learning platform RIF (RIF is the abbreviation for the German word "RaumIntelligenzFörderung") for training and diagnosing spatial thinking skills.

Therefore, when designing the RIF platform, it was a major concern to integrate as many different types of tasks as possible into the platform. The wide range of the 1.600 tasks has certainly been made possible by the fact that more than 30 members of the RIF team have been involved in the task development process and have made valuable contributions. On the one hand, 15 members of the ADI Geometry Group (a group of Austrian geometry experts; `https://www.adi3d.at`) were involved, and on the other hand at least 15 students from the University of Salzburg who developed and evaluated numerous tasks (mostly) in the context of writing their bachelor or master thesis (`https://rif4you.eu/7.2_ueberuns.php?spr=en`). In addition, two PhD students of the MSCA-ITN project SellSTEM (`https://sellstem.eu`), Natalia Segura Caballero and Eleni Lagoudaki, also developed and evaluated numerous new tasks for RIF.

Newly developed tasks were only incorporated into RIF, if they proved to be scientifically successful after being evaluated on several thousand students with the help of the website `https://geometriedidaktik.at`. About 20% of the developed tasks were eliminated due to non-fitting evaluation results and almost all tasks were revised based on the indications and feedback from the evaluation process and only then integrated into the learning platform. The involvement of more than 30 task developers, each contributing their unique individual approaches and ideas, has resulted in the great variety of task types that are now integrated into RIF. This diversity in tasks is certainly one of the key factors in the success of RIF.

In general, the platform RIF was programmed as an online platform for training spatial thinking skills which can be used for free by every user. To date (January 2024), more than 2.5 million tasks have been solved by more than 60.000 students from 33 countries around the world on the platform (see the interactive world map at `https://geometriedidaktik.at/en/3076-2/rif-countries/`). The mission of the team of developers of RIF is to provide high quality education for spatial thinking skills for free for everyone, no matter where students are located around the world and no matter how much money their parents earn. The platform is a contribution to fostering STEM education around the world because there is evidence, that spatial thinking skills are one of the key abilities to be able to work successfully in the STEM field [43]. Therefore, RIF offers extensive training and diagnostic tools in the form of various task groups for primary and secondary students as well as university students. RIF is available in English (`https://rif4you.eu/en/`), German (`https://rif4you.eu/`), and Spanish (`https://rif4you.eu/es/`). The task groups usually contain 30 tasks and students need between 6 to 13 minutes to complete the tasks of one task group. The task groups

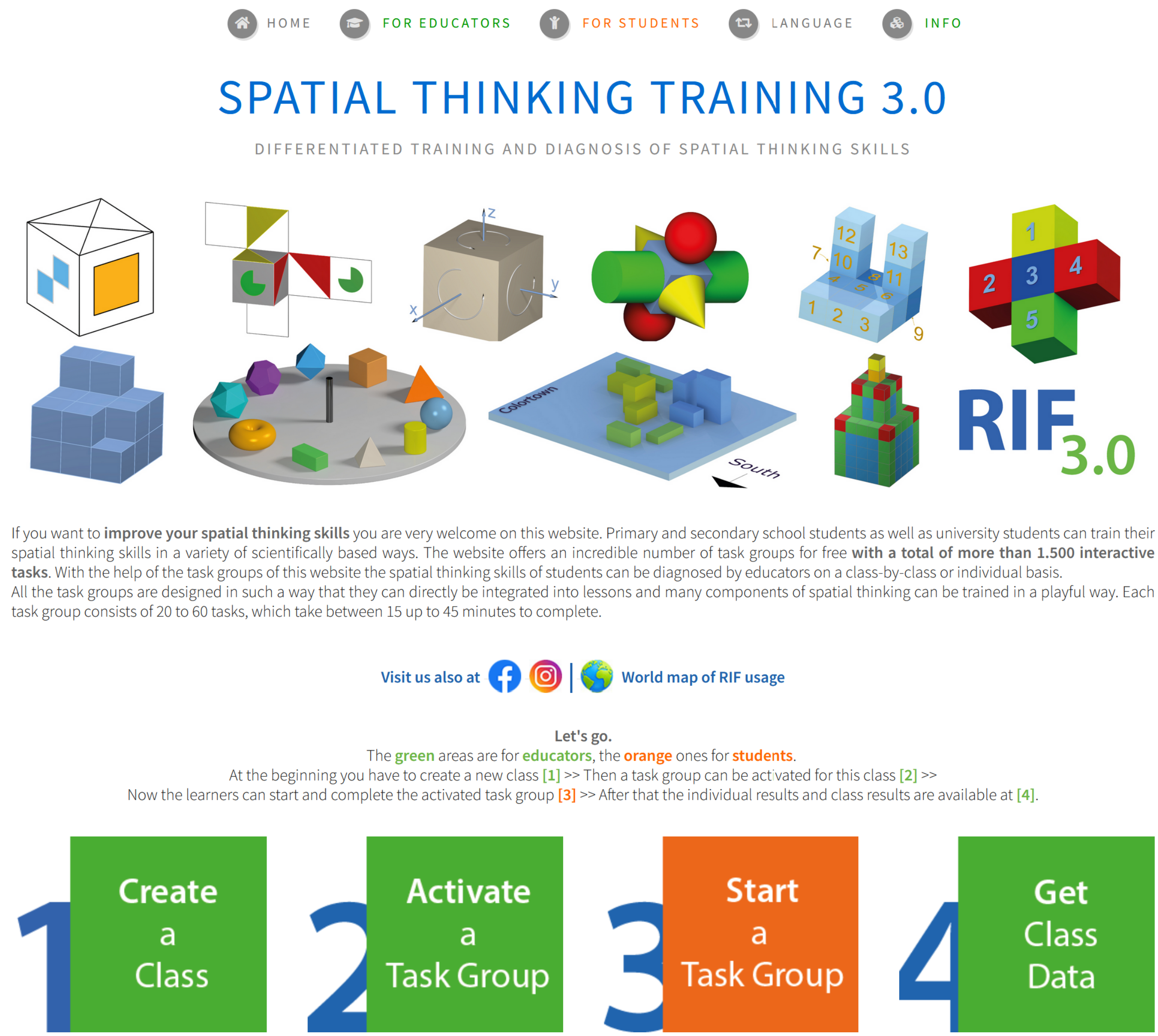

Figure 1: Screenshot from the English version of the online spatial thinking training and diagnosis platform RIF

are arranged in nine different areas of spatial thinking. Two models serve as the scientific framework for that structure of RIF: For the task groups in the domains 1 to 5, the first five basic practices of spatial thinking [22, 33] were used as a scientific basis. These basic practices are visualization (VI), form constancy (FC), position in space (PS), transformations in space (TS), and object combinations (OC). The task groups with higher difficulty in the domains 6 to 9 are structured according to the model of spatial ability, which identifies four subcomponents of this intelligence facet. The four subcomponents are spatial visualization (SV), spatial relations (SR), mental rotation (MR), and spatial orientation (SO). The model with the four components of spatial thinking [21] was adopted from the model of Maier [18]. Detailed analyses of Maier's approach showed that the four factors visualization, spatial relation, mental rotation, and spatial orientation had also been formulated in three up to nine other models of other researchers [20]. Only the factor spatial perception was just included in the model of Linn and Petersen [15]. The description of this factor according to Linn and Petersen defines the factor spatial perception as the ability to identify the horizontal and the vertical. This very specific ability is considered to be an integrative part of the factor spatial orientation by Thurstone [40]. Thus, spatial perception is no longer considered a separate factor and is therefore not included in the RIF platform.

The logical workflow with this website includes the following four steps: (1) Creating of a class by the educator. (2) Activating one task group by the educator for the class. (3) Starting the activated task group by the students and completing all the included tasks. (4) Retrieving the class results by the educator and the individual results by the students (see the four large square buttons at the bottom in Figure 1). Students can access their individual spatial thinking profile online, which provides the performance at the nine different domains of spatial thinking. Educators can access all the spatial thinking profiles from their students.

2 Age-Related, Domain-Related and Gender-Specific Analyses

The goal of the analysis of the large dataset of the online spatial thinking platform RIF is, to get information about the following questions:

- Do spatial thinking skills change (increase, decrease) with age?
- Are gender differences recognizable?
- If yes, in which age groups and in which domains of spatial thinking are these gender differences recognizable and how big are the differences?

2.1 Methodology

From November 2019 to November 2022, four different areas of spatial thinking could be trained and diagnosed at RIF. These were spatial visualization, spatial relations, mental rotation, and spatial orientation. The tasks of these areas are recommended for students 13 years and older. In November 2022, five new domains were added: visualization, form constancy, position in space, transformations in space, and object combinations. The tasks in these five areas are primarily intended for learners aged 7 to 12. It is also due to this chronological order of the implementation of the task areas in RIF that (as of May 11, 2023, the date from which the data for this paper originate) 92.45% (58,619 task groups) of the tasks have been completed from SV, SR, MR, and SO, i.e., from exactly those areas that have already been on the platform since 2019. Only 7.55% (4,788 task groups) of the tasks have been completed so far from the VI, FC, PS, TS and OC areas. The reason for this is certainly that these tasks have been on the platform only for about 5 months. Therefore, the initial evaluations of the RIF data discussed below, regard only the data from the four domains SV, SR, MR, and SO, which represents a sufficient and stable data basis for reliable statements.

There are 3,815 classes from 33 countries working with RIF. The vast majority of classes (3,391; 89%) are from Austrian students. The other 432 classes (11%) are from 32 countries from all continents. In the analyses of this paper all classes were considered. Because most of the classes are from Austria, the analyses represent mostly the current situation in Austria.

RIF stores the following anonymous data from each student: student code, age, gender, handedness, number of brothers/sisters, date of completing a task group, performance at each task, and time taken to complete the task groups. Therefore, RIF allows the analysis and description of correlations between all those data. Here we present the results of the descriptive analyses of the collected data, examining students' performance in relation to age, the different domains of spatial thinking (integrated in RIF) and gender.

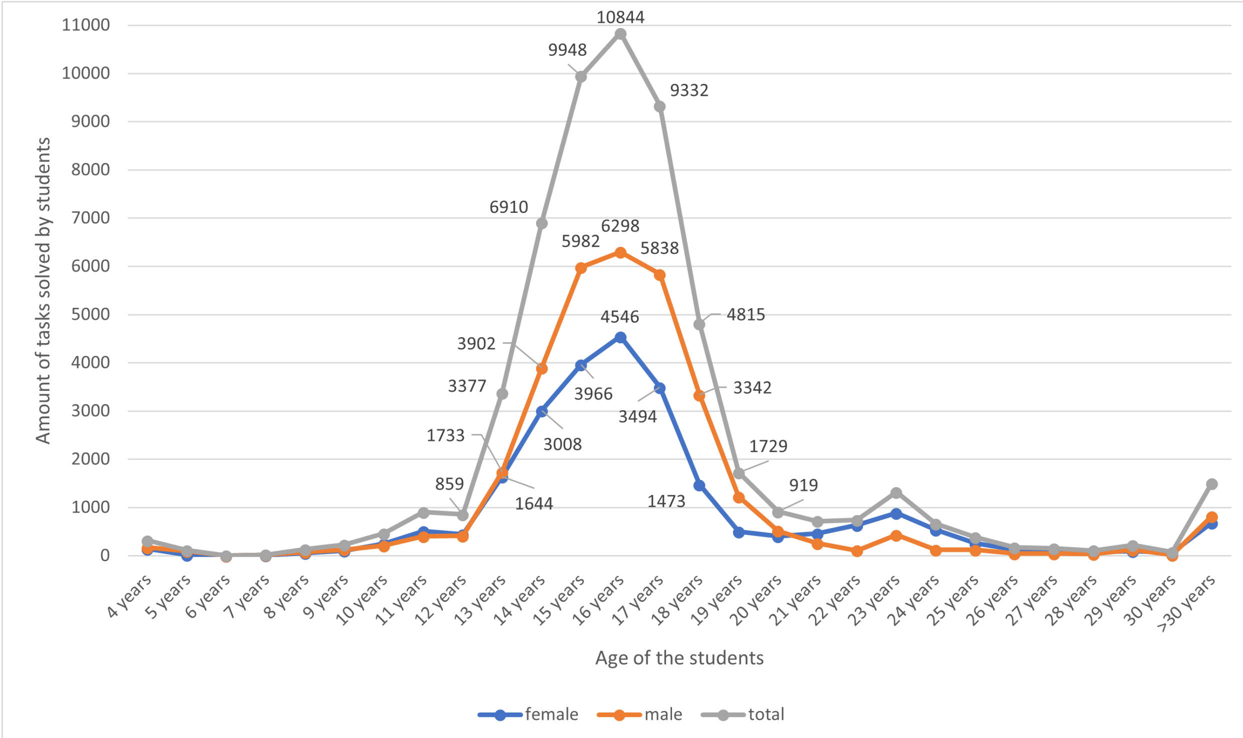

Figure 2: Age distribution of the users of the platform RIF

2.2 Results

The basis of the following analyses were the results from 58,619 completed task groups at RIF until May 2023. When looking at the age of RIF users, it becomes apparent that the vast majority of learners are between 12 and 27 years old (Figure 2). In order to make only viable statements in age-related analyses, the investigation in this article was restricted to the age group of 12 to 27-year-olds ($N = 53,647$; $f = 22,902$; $m = 30,745$; age mean = 17.26 years).

Figure 3 shows the average percentage of correctly solved tasks by 12- to 27-year-olds in the four domains spatial visualization, spatial relations, mental rotation, and spatial orientation. The performance of users increases with age. Starting at 44.68% among 12-year-old girls to 74.32% among women in the 24- to 27-year-old age group. Boys improve from 47.69% (12-year-olds) to about 74% among 18- to 27-year-olds. In the age from 14 to 17 years, hardly any increase can be observed for both genders (Figure 3).

The overall evaluation of the performance of RIF users with regard to gender shows a slightly better performance of boys compared to girls over the age range of 12 to 17 years. No performance differences can be detected in the age range 18 to 27. The average quantified difference in performance between 12 and 17-year-olds is 2.63%. (Figure 3). This is a very small difference that does not allow any conclusions about substantial gender differences.

In the following, to elucidate differences, we examine the gender-specific performance developments by age group according to the spatial thinking domains SV, SR, MR, and SO. This differentiation between the domains shows significant gender differences. In the area of mental rotation, greater differences between the genders are evident across all age groups. Boys (between 12 and 27 years) perform 6.24% better than girls in the area of mental rotation (Figure 4). This is a remarkable and substantial difference. On the other hand, boys and girls are *cum grano salis* equally good in the three areas (SV, SR, and SO) of spatial thinking. The

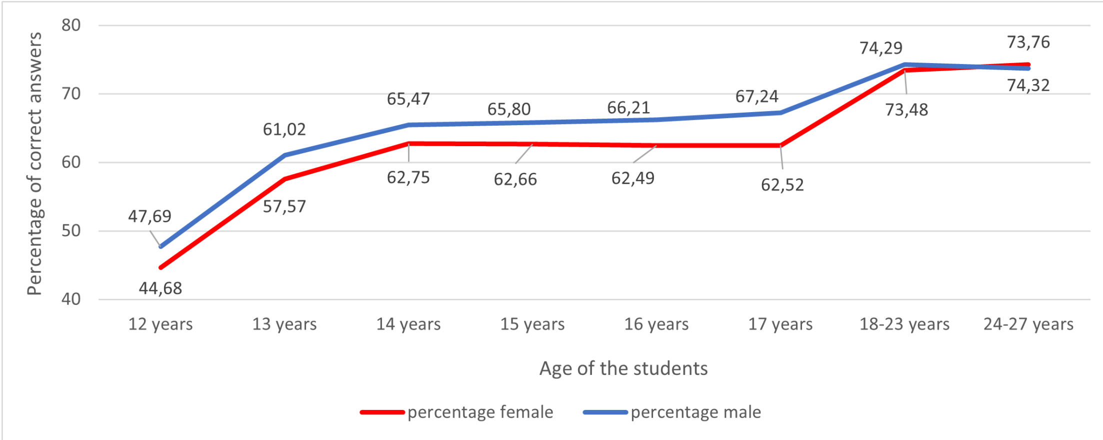

Figure 3: Age-related performance of users at the domains spatial visualization, spatial relations, mental rotation, and spatial orientation

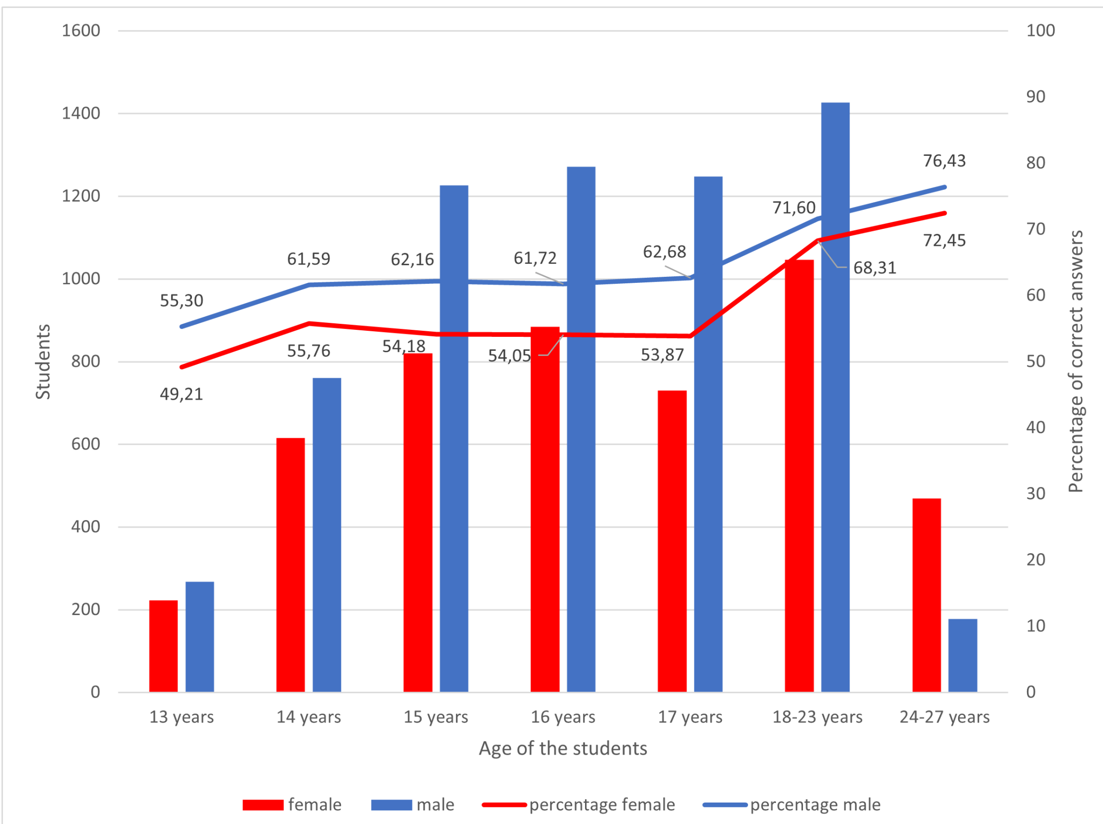

Figure 4: Gender differences in mental rotation

average difference in theses domains is only 1.23% (Figure 5).

A deeper look at the gender differences at the domain mental rotation shows that 13 and 14 year old students have a gender difference of about 6% (13 year old: 6.09%; 14 year old: 5.84%), 15 to 17 year old students have a gender difference of about 8% (15 year old: 7.98%; 16 year old: 7.67%; 17 year old: 8.80%), and older students have much smaller gender differences in mental rotation (18 to 23 year old: 3.29%; 24-27 year old: 3.98%; older than 30 year old: 1.38%). The biggest gender gap between boys and girls can be recognized for the 15-

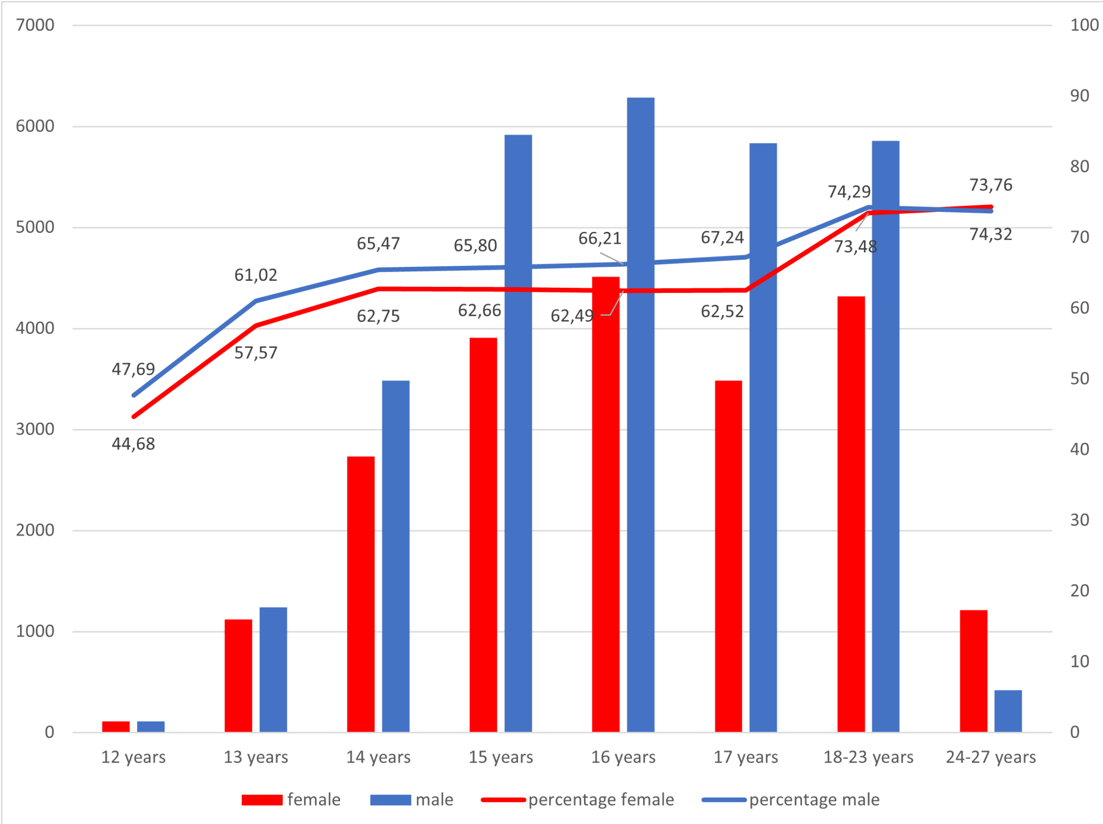

Figure 5: Gender differences in spatial visualization, spatial relations, and spatial orientation

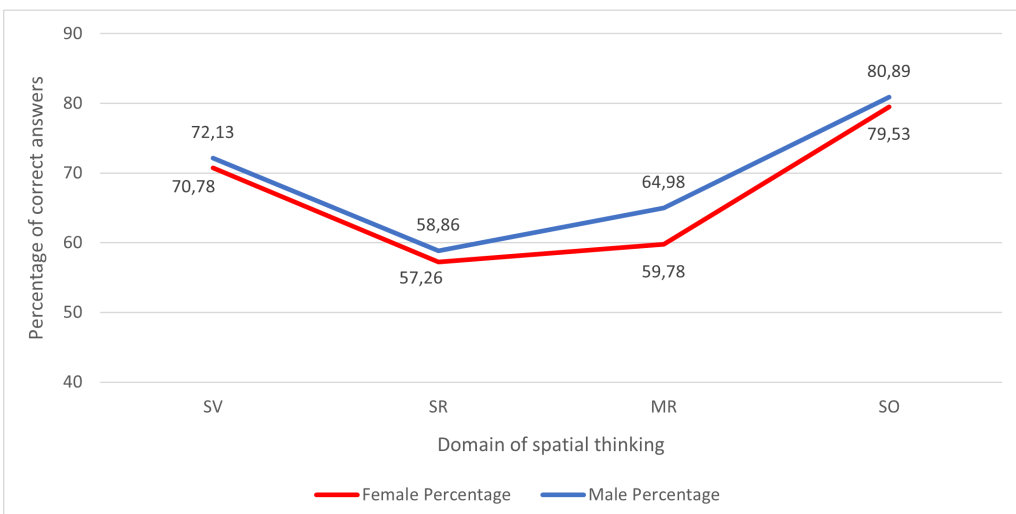

Figure 6: Gender differences in spatial visualization (SV), spatial relations (SR), mental rotation (MR), and spatial orientation (SO) ordered by these four areas of spatial thinking

to 17-year-old students and it seems that this gender difference decreases considerably the older the students are.

When looking at the gender differences structured by the domains of spatial thinking and independent of age, the substantial difference between both genders is also clearly evident only in the area of mental rotation (Figure 6).

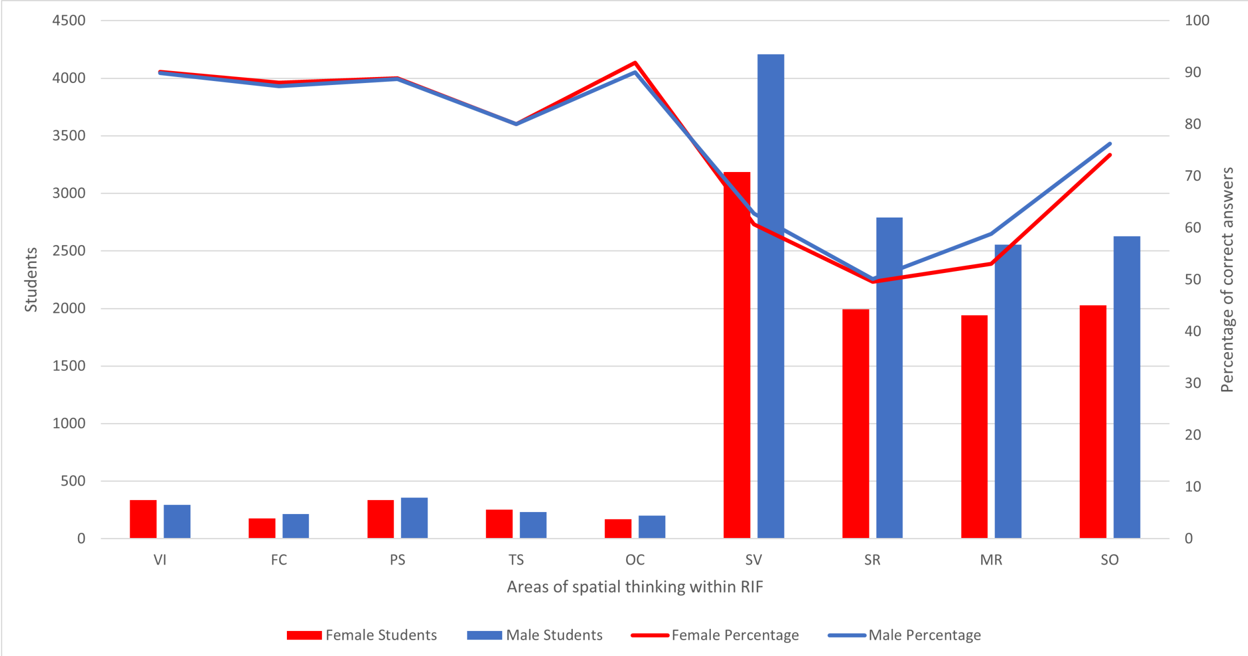

Figure 7: Gender differences in all nine spatial thinking domains of RIF: visualization (VI), form constancy (FC), position in space (PS), transformations in space (TS), and object combinations (OC), spatial visualization (SV), spatial relations (SR), mental rotation (MR), and spatial orientation (SO)

The areas VI, FC, PS, TS and OC, which were developed especially for younger students from the age of 7, and which have only been available in RIF for 5 months, have "only" 4,788 users (as of May 11, 2023). Therefore, it is not yet possible to make any reliable differentiated evaluations of age groups, areas and genders for these areas. However, initial trends indicate that girls and boys perform equally good in these areas (see Figure 7).

3 Discussion

The analyses of the 53,647 data from the RIF online platform for spatial thinking skills training, which come from completed task groups (until May 2023) in the domains of spatial visualization, spatial relations, mental rotation, and spatial orientation of students from 12 to 27 years, show that girls and boys perform equally well in the three domains of spatial visualization, spatial relations, and spatial orientation. The average difference in these domains is just 1.23%. This difference is much too small to infer substantial real differences in spatial thinking between girls and boys.

Only in the domain of mental rotation boys are 6.24% better than girls, which is a remarkable and substantial gender difference. The biggest difference between boys and girls in the domain of mental rotation is noticeable at the age of 15 to 17 (about 8%). The students younger than 15 have smaller gender differences in mental rotation ($\sim 6\%$). Students older than 17 have the smallest gender differences in mental rotation ($\sim 3\%$) and it seems that the difference decreases considerably the older the students are because students older than 30 years have only a gender difference of 1.38%.

The first glances at the data of the other five domains of spatial thinking (visualization, form constancy, position in space, transformations in space, and object combinations), which have been available in RIF since November 2022, suggest that girls and boys are equally good in these domains as well. Since relatively little data is available in these areas (see Figure 7), we do not yet infer any robust results from them.

Gender differences in mental rotation ability are confirmed in the literature [13, 14, 35]. In the mentioned literature, some possible causes for these performance differences are discussed. Among others, different solution strategies, dependencies on the size of the rotation angle, dependencies on the figures used, gender-specific experience differences, gender-specific different brain structures, and different hormonal situations are suspected.

The analyses of the data also show that the probability of students solving tasks successfully increases with increasing age. This suggests that spatial ability is not only genetically predisposed, but also develops at least during the first 30 years of life. No assumption can be made about the further development of spatial thinking skills since RIF deals mainly with students up to the age of 30. These results confirm the current literature, in which researchers have found that spatial thinking skills are not only genetically inherited but can also be significantly improved over the course of a lifetime through training [27].

One of the strengths of the analysis presented in this paper is the very large data set which was used (53,647 data). Another strength is the completeness of the data, because RIF works only with mandatory fields that must be filled in by the students and also all the tasks of one task group have to be completed by the students. The limitation of the analysis of the RIF data is that there is no possibility to control if the data come from real classes or from fake users. Some fake users and therefore some fake data will be part of the data set of RIF, but due to the very large amount of data, it is expected that the few fake data should have no influence on the results.

There is hardly any literature that has investigated the differences in gender across age groups. Some studies conclude that the gender differences (mainly in the domain of mental rotation) occur from the age of puberty on [29, 41]. There are no known studies that provide results on whether spatial abilities – especially at the domain of mental rotation – change over the course of life. A meta-study would be needed to identify differences between the age groups. This would shed more light on the possibly changing gender differences with increasing age. Therefore, this study could be a starting point for further research that addresses the issue of age-specific gender differences in mental rotation and other areas of spatial thinking. The analyses we present in this paper clearly indicate that the gender differences in the area of mental rotation start to narrow significantly again from the age of around 17 and that the difference is much smaller with $\sim 3\%$ than for young children (< 12 years) where the difference is $\sim 6\%$.

One of the consequences of these analyses is the recommendation that tests of spatial ability should not be limited to the area of mental rotation but should cover as many different areas of spatial thinking as possible, since testing only in the area of mental rotation ability would automatically favor male test subjects. The RIF platform is currently being used by more and more students, so that in a few months a significantly larger dataset will be available in order to be able to present even clearer results in the four areas of spatial ability presented here and to be able to publish the first results of analyses of the five domains of RIF, which were integrated into the platform in November 2022 (visualization, form constancy, position in space, transformations in space, and object combinations).

Further research should investigate how the gender differences in the different areas of spatial abilities change over the course of age. It would also be interesting to see what kind of training could reduce the differences. Furthermore, it would be important that research also seeks to identify and investigate possible new spatial skills that our modern society needs (such as dynamic skills).

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References

[1] M. Annett: *Spatial ability in subgroups of left- and right-handers.* British Journal of Psychology **83**, 493–515, 1992.

[2] J. Buckley, N. Seery, and D. Canty: *Spatial cognition in engineering education: Developing a spatial ability framework to support the translation of theory into practice.* European Journal of Engineering Education **44**, 164–178, 2019. doi: 10.1080/03043797.2017.1327944.

[3] P. J. Caplan, G. M. MacPherson, and P. Tobin: *Do sex-related differences in spatial ability exist? A multilevel critique with new data.* American Psychologist **40**, 786–799, 1985.

[4] P. J. Caplan, G. M. MacPherson, and P. Tobin: *The magnified molehill and the misplaced focus: Sex-related differences in spatial ability revisited.* American Psychologist **41**, 1016–1018, 1986.

[5] J. B. Carroll: *Human cognitive abilities. A survey of factor-analytical studies.* Cambridge University Press, New York, 1993.

[6] M. B. Casey and M. M. Brabeck: *Exception to the male advantage on a spatial task: Family handedness and college major as factors identifying women who excel.* Neuropsychologia **27**, 689–696, 1989.

[7] F. Galton: *Generic images.* The Nineteenth Century **6**(1), 157–169, 1879.

[8] G. Gittler and J. Glück: *Differential Transfer of Learning: Effects of Instruction in Descriptive Geometry on Spatial Test Performance.* Journal for Geometry and Graphics **2**(1), 71–84, 1998.

[9] G. Gittler, M. Jirasko, U. Kastner-Koller, C. Korunka, and A. Al-Roubaie: *Intelligenzförderung durch Schulunterricht: Darstellende Geometrie und räumliches Vorstellungsvermögen: Die Seele ist ein weites Land.* WUV Universitätsverlag, 1994.

[10] J. Glück, H. Kaufmann, A. Dünser, and K. Steigbügl: *Geometrie und Raumvorstellung – Psychologische Perspektiven.* Informationsblätter der Geometrie (IBDG) **24**(1), 4–11, 2005.

[11] R. Gorska, S. A. Sorby, and C. Leopold: *Gender differences in visualization skills-an international perspective.* Engineering Design Graphics Journal **62**, 9–18, 1998.

[12] J. P. Guilford: *The Nature of Human Intelligence.* McGraw-Hill, New York, 1967.

[13] M. Hegarty and D. Waller: *Individual Differences in Spatial Abilities.* In P. Shah and A. Miyake, eds., *The Cambridge Handbook of Visuospatial Thinking*, 121–169. Cambridge University Press, 2012.

[14] P. Jansen, A. Schmelter, C. Quaiser-Pohl, S. Neuburger, and M. Heil: *Mental rotation performance in primary school age children: Are there gender differences in chronometrical tests?* Cognitive Development **28**, 51–62, 2012.

[15] M. C. Linn and A. C. Petersen: *Emergence and characterization of sex differences on spatial ability: a meta-analysis.* Child Development **56**, 1479–1498, 1985.

[16] D. F. Lohman: *Spatial abilities: A review and re-analysis of the correlational literature (Technical Report No. 8).* Tech. rep., Stanford University, Aptitude Research project, Stanford, CA, 1979.

[17] E. E. Maccoby and C. N. Jacklin: *The psychology of sex differences.* Stanford University Press, Stanford, CA, 1974.

[18] H. Maier: *Räumliches Vorstellungsvermögen: Komponenten, geschlechtsspezifische Differenzen, Relevanz, Entwicklung und Realisierung in der Realschule*, vol. 493 of *Europäische Hochschulschriften: Reihe 6, Psychologie.* 1994.

[19] G. Maresch: *Strategies for Assessing Spatial Ability Tasks.* Journal for Geometry and Graphics **18**(1), 125–132, 2014a.

[20] G. Maresch: *Spatial Ability – The Phases of Spatial Ability Research.* Journal for Geometry and Graphics **17**(2), 237–250, 2014b.

[21] G. Maresch: *How to develop spatial ability? Factors, Strategies, and Gender Specific Findings.* Journal for Geometry and Graphics **19**(1), 133–157, 2015.

[22] G. Maresch: *Die Grundroutinen des räumlichen Denkens und Handelns.* In *Neue Impulse in der Naturwissenschaftsdidaktik*, 121–133. Waxmann, Münster, 2020.

[23] G. Maresch and S. Sorby: *Perspectives on Spatial Thinking.* Journal for Geometry and Graphics **25**(2), 271–293, 2021.

[24] M. McGee: *Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences.* Psychological Bulletin **86**, 889–918, 1979.

[25] W. F. McKeever: *Hormone and hemisphericity hypotheses regarding cognitive sex differences: Possible future explanatory power, but current empirical chaos.* Learning and Individual Differences **7**, 323–340, 1995.

[26] K. S. Mix, S. C. Levine, Y. L. Cheng, C. Young, D. Z. Hambrick, R. Ping, and S. Konstantopoulos: *Separate but correlated: The latent structure of space and mathematics across development.* Journal of Experimental Psychology: General **145**(9), 1206–1227, 2016. doi: 10.1037/xge0000182.

[27] D. R. Montello, K. E. Grossner, and D. G. Janelle, eds.: *Space in mind: Concepts for spatial learning and education.* MIT Press, Cambridge (Massachusetts), 2014.

[28] Y. Moon, H. Jo, J. Kim, and J. Ryu: *Exploring gender differences in spatial orientation ability on representing cognitive map.* International Journal of Psychology and Behavioral Sciences **6**, 91–98, 2016. doi: 10.5923/j.ijpbs.20160602.09.

[29] S. Neuburger, P. Jansen, M. Heil, and C. Quaiser-Pohl: *Mental rotation in pre-adolescence: Does the gender difference in elementary-school children depend on grade and stimulus type?* Personality and Individual Differences **50**, 1238–1242, 2011.

[30] N. Newcombe and J. S. Dubas: *A longitudinal study of predictors of spatial ability in adolescent females.* Child Development **63**, 37–46, 1992.

[31] N. Newcombe and T. Shipley: *Thinking About Spatial Thinking: New Typology, New Assessments.* In J. Gero, ed., *Studying Visual and Spatial Reasoning for Design Creativity.* Springer, Dordrecht, 2014. doi: https://doi.org/10.1007/978-94-017-9297-4_10.

[32] N. S. Newcombe: *The puzzle of spatial sex differences: Current status and prerequisites to solutions.* Child Development Perspectives **14**, 251–257, 2020. doi: 10.1111/cdep.12389.

[33] A. Posamentier, G. Maresch, B. Thaller, C. Dorner, R. Geretschläger, C. Spreitzer, and D. Stuhlpfarrer: *Geometry in our Three-Dimensional World.* World Scientific Publishing, Singapore, New York, 2021.

[34] C. Quaiser-Pohl, P. Jansen, J. Lehmann, and B. M. Kudielka: *Is there a relationship between the performance in a chronometric mental-rotations test and salivary testosterone and estradiol levels in children aged 9–14 years?: Mental rotation and salivary hormones in (pre-)puberty.* Dev. Psychobiol. **58**, 120–128, 2016. doi: 10.1002/dev.21333.

[35] C. Quaiser-Pohl, S. Neuburger, M. Heil, P. Jansen, and A. Schmelter: *Is the Male Advantage in Mental-Rotation Performance Task Independent? On the Usability of Chronometric Tests and Paper-and-Pencil Tests in Children.* International Journal of Testing **14**(2), 122–142, 2014. doi: 10.1080/15305058.2013.860148.

[36] D. F. Sherry and E. Hampson: *Evolution and the hormonal control of sexually-dimorphic spatial abilities in humans.* Trends in Cognitive Sciences **1**, 50–56, 1997.

[37] S. Sorby and N. Veurink: *Are the visualization skills of first year engineering students changing?* In *2010 Annual Conference & Exposition.* Louisville, Kentucky, 2010.

[38] E. Souvignier: *Förderung räumlicher Fähigkeiten – Trainingsstudien mit lernbeeinträchtigten Schülern*, vol. 22 of *Pädagogische Psychologie und Entwicklungspsychologie.* 2000.

[39] L. Thurstone: *Primary Mental Abilities.* The University of Chicago Press, Chicago, Illinois, 1938.

[40] L. L. Thurstone: *Some primary abilities in visual thinking.* Tech. rep., Psychometric Laboratory Research Report No. 59, University of Chicago Press, Chicago, 1950.

[41] C. Titze, P. Jansen, and M. Heil: *Mental rotation performance and the effect of gender in fourth graders and adults.* European Journal of Developmental Psychology **7**, 432–444, 2010.

[42] D. Voyer, S. Voyer, and M. P. Bryden: *Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables.* Psychological Bulletin **117**, 250–270, 1995.

[43] J. Wai, D. Lubinski, and C. P. Benbow: *Spatial Ability for STEM Domains: Aligning Over 50 Years of Cumulative Psychological Knowledge Solidifies Its Importance.* Journal of Educational Psychology **101**(4), 817–835, 2009. doi: 10.1037/a0016127.

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