VR Social Skills Training in Autism Spectrum Disorder

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Poor social skills in autism spectrum disorder (ASD) are associated with reduced independence in daily life. Current interventions for improving the social skills of individuals with ASD fail to represent the complexity of real-life social settings and situations. Virtual reality (VR) may facilitate social skills training in social environments and situations similar to those in real life; however, more research is needed to elucidate aspects such as the acceptability, usability, and user experience of VR systems in ASD. Twenty-five participants with ASD attended a neuropsychological evaluation and three sessions of VR social skills training, which incorporated five social scenarios with three difficulty levels. Participants reported high acceptability, system usability, and user experience. Significant correlations were observed between performance in social scenarios, self-reports, and executive functions. Working memory and planning ability were significant predictors of the functionality level in ASD and the VR system's perceived usability, respectively. Yet, performance in social scenarios was the best predictor of usability, acceptability, and functionality level. Planning ability substantially predicted performance in social scenarios, suggesting an implication in social skills. Immersive VR social skills training in individuals with ASD appears to be an appropriate service, but an errorless approach that is adaptive to the individual's needs should be preferred.

Keywords: virtual reality ; training ; autism ; social skills ; social cognition

1. Introduction

Autism spectrum disorder (ASD) is a lifelong complex neurodevelopmental disorder that significantly impairs individuals' verbal and nonverbal communication, social interactions, and behaviours (i.e., exhibition of restricted interests, repetitive and unusual sensory–motor behaviours) [1]. Prevalence estimates of ASD have increased over time, and a recent systematic review [2] reported a median global prevalence (ranging within and across regions) of 100/10,000. ASD presents a striking sex difference, as males are more likely to be affected relative to females (3:1 ratio) [3]. The ASD aetiology is suggested to be multifactorial, as both genetic and non-genetic factors (e.g., prenatal/perinatal) may play a crucial role in the manifestation of the disorder (see [4] for a review). In contrast to its first description, ASD is now regarded as a spectrum that spans from very mild to severe [5], as symptoms manifest differently in each individual based on their functionality level (level 1—requiring support; level 2—requiring substantial support; level 3—requiring very substantial support). Nevertheless, several individuals with ASD (not all) require some kind of support throughout their life [5]. Even individuals with high-functioning ASD, similar to other individuals at the mild and lower end of the spectrum, present social skill deficits across the lifespan (up to adulthood). Adults with ASD are likely to experience problems in social and everyday life functioning due to a lack of ecological training and intervention programmes during childhood and adolescence [6].

2. Social Skills and Executive Functions in ASD

Adults with ASD have been found to experience social isolation, loneliness, and social anxiety (e.g., [7]) due to their deficient social skills, such as atypical gaze/poor eye contact, less conversational involvement, inappropriate affect, reduced verbal fluency (e.g., [8][9]), poor understanding of social cues, and difficulties in initiating and maintaining social conversation/communication [10]. The social skill deficits in individuals with high-functioning ASD are mainly attributed to impairments in cognitive components such as executive functions (EFs) (e.g., [11]) or cognitive processing speed (e.g., [12]). Indeed, impaired EF, which refers to high-order, goal-directed cognitive processes that control behaviour, thought, and emotions, is another salient characteristic of the spectrum [13]. The EF construct is seen as an umbrella term that includes abilities such as inhibition, working memory, and planning (not an exhaustive list; see [14][15] for a more detailed EF discussion). Two recent meta-analyses [16][17] demonstrated broad EF impairment in ASD, as deficits have been consistently found in several EF aspects (e.g., inhibition, working memory, cognitive flexibility, and planning) across the lifespan.

To implement effective interventions, research over the last decade has aimed to identify which EF aspects contribute to the manifestation of social skills in ASD [11][18], as it is suggested that higher-order cognitive regulation is required for social interactions [19]. EFs have been proposed to support the processing and manipulation of information from one's and others' perspectives to facilitate social interaction and communication skills [20]. Such associations are understudied in adulthood in ASD. Limited evidence from childhood and adolescence has shown that performance-based measures of EF (e.g., auditory attention and inhibition/switching) are related to social deficits in ASD (e.g., [21][22]), while ratings-based EFs such as initiation, cognitive flexibility, and working memory were found to be related to adaptive social skills in ASD [23][24]. A recent study [18] also demonstrated significant associations between ratings-based EFs (self-monitoring) and selective social skills (social inferencing and social knowledge) in ASD. It should be noted, though, that none of the aforementioned studies, despite their findings, used in vivo measures of social functioning or a naturalistic context of assessment. Social skills have been theoretically proposed to also depend on social cognition aspects such as mental state/emotion recognition [25], but as these aspects are not consistently associated with social impairment in ASD [26], the extent to which socio-cognitive abilities are associated with the social difficulties in ASD has been debated over the years. Given these potential associations among social cognition and social skills, EFs and social skills, and EFs and social cognition (e.g., [27][28][29]), it has been suggested that EFs may contribute to social skills both directly and indirectly [30]. Social cognition aspects are likely to partially mediate the association between EFs and social skills; perhaps no single cognitive mechanism in ASD can explain the various social difficulties, as previously argued [31], as there may be several factors potentially contributing to social skills (e.g., poor emotion regulation) that could also explain the social and behavioural problems in ASD (e.g., [32]).

3. Assessment, Training, and Intervention in ASD

The assessment of ASD impairments is critical for identifying potential difficulties and weaknesses when implementing interventions. For example, widely used measures of social functioning include the Social Responsiveness Scale (a measure of general social ability [33][34]), Reading the Mind in the Eyes test (a measure of mental state/emotion recognition [35]), and the Autism Diagnostic Observation Schedule (a measure of social interaction, communication, and play [36][37]). Taking into consideration the tremendous impact of the aforementioned cognitive and social impairments on the everyday lives of individuals with ASD, suitable intervention and training programmes are needed [38]. Targeting cognitive deficits, cognitive training exercises in adults with ASD are usually implemented to enhance performance through repeated practice on EF tasks (e.g., [39][40]). Cognitive training exercises encompass various intervention methods, such as pen-and-paper tasks, downloadable tools, and logical games. Given the EF contribution to several aspects of social functioning, targeting specific EF aspects is thought to improve the effectiveness of training interventions in ASD [41]. However, it should be noted that cognitive training studies in ASD have been designed only in recent years, and thus, their limited and mixed results as well as their lack of ecological validity are the subject of ongoing discussion (e.g., [42][43][44]).

When it comes to social skills, several different strategies have been used in training and intervention programmes to enhance social functioning (usually social interaction and communication) in adults with ASD. For example, strategies such as social stories and social scripts, behavioural modelling and role-playing demonstrations, video modelling, and self-modelling (e.g., [45]) in the context of didactic lessons to enhance conversational skills, developing friendships, the appropriate use of humour, dating, and handling embarrassing feedback and peer pressure (e.g., [46]) have been used in ASD. Most psychosocial intervention and training programmes in ASD, however, are thought to yield limited benefits [47] because of their limited ecological validity, which does not permit the generalisation of the outcomes to everyday life [48] [49]. The limitations of the aforementioned methods are thought to likely arise because of the ASD literature's tendency to examine social (and/or cognitive) deficits as isolated and individual features without evaluating how they manifest in real-life contexts, in which outcomes are influenced by relational dynamics as well [41][50]. For that reason, computing technology with more naturalistic set-ups and role play is a significantly effective training and intervention medium for individuals with ASD [51].

4. Ecological Validity, Virtual Reality Assessments, and Interventions

Ecological validity refers to the verisimilitude (i.e., the likeness to everyday life) and veridicality (i.e., the association between the observed and real-life performance) of a neuropsychological tool, which subsequently allows the generalisation to everyday life [52]. In contrast to paper-and-pencil or computerised approaches, which incorporate static and simplistic testing and training environments and stimuli, immersive virtual reality (VR) facilitates the attainment of enhanced ecological validity and pleasantness [53]. Immersive VR neuropsychological tools may thus contribute to the understanding of everyday functionality (e.g., [54][55]) and improve everyday physical and cognitive functioning (e.g., [56][57]

[58]). In the context of VR interventions in ASD, immersive VR technology facilitates the creation of simulated environments that can be used to help individuals with ASD improve social skills, communication, and behaviour [59][60][61][62]. These interventions aim to provide individuals with ASD with a safe and controlled environment in which to practice and develop skills, as well as to reduce the anxiety and stress associated with real-world interactions [60]. VR interventions can include activities such as role-playing social scenarios, virtual social skills training, and virtual exposure therapy. However, the effective implementation of immersive VR for research and clinical purposes requires technological competence [63]. An inappropriate conceptualisation of VR training may have negative ramifications and compromise its otherwise beneficial outcomes [62].

Nevertheless, several VR applications have efficaciously been implemented for assessment and intervention purposes. The VR Everyday Assessment Lab assesses everyday memory (prospective and episodic), attention (visuospatial and auditory), and EFs (planning and multitasking) and has been found to be a valid and substantially more pleasant testing experience [53] that is representative of the everyday functionality of adults [54][55]. The ClinicaVR: Classroom-CPT is a VR classroom that examines selective and sustained attention and inhibition, and it has been validated in children and adolescents [64]. Regarding interventions in ASD, there is preliminary evidence postulating its feasibility for being adopted in clinical and educational environments [59][65]. Additionally, the use of social stories in VR has been evaluated by clinicians for implementation in clinical and educational settings for social skills training in children with ASD [66]. Preliminary evidence suggests that VR software may improve the conversational [61], problem-solving, and communication skills of children with ASD [67]. After a VR training protocol, children with ASD showed significant improvements in emotion expression and regulation and socioemotional reciprocity [68]. Comparably, two more studies [69][70] reported a substantial enhancement of social skills in children with ASD after they attended VR-based training sessions. It is important, however, to underline that VR interventions in ASD are still considered an emerging field, and more research is needed to fully understand their efficacy, usability, and the provided user experience, as well as their acceptability by individuals with ASD [59][60][62]. Furthermore, the relationship between performance in VR social scenarios and cognitive functioning has not yet been investigated. Finally, while there are several VR applications used in children and/or adolescents with ASD, none of the aforementioned VR applications was designed for or implemented in adults with ASD.

5. VRESS

The VR Enhancement of Social Skills (VRESS) was developed in line with the guidelines for developing VR software for research and clinical applications in the field of psychology [71]; these guidelines have been found to produce VR software that meets the criteria of the American Academy of Clinical Neuropsychology (AACN) and the National Academy of Neuropsychology (NAN) [72]. VRESS incorporates social scenarios that are exemplary of adult activities and common in daily life, such as renewing one's subscription to the gym, selecting a movie and buying a ticket at the cinema, browsing the available options and purchasing a smartphone at the phone store, attending a seminar class and interacting with the instructor and the co-students, and attending a job interview and responding to the interviewers' questions. The social scenarios were designed in line with the guidelines of Gray and Garand [73] for providing social stories that provide individuals with ASD (i.e., the learners) a visual representation and a description of a situation or activity to prepare and instruct them on what to expect, as well as the underlying reasons for this matter. Thus, the social scenarios of VRESS are descriptive rather than directive. The social stories were designed for individuals with ASD to comprehend and apply the intricacies of interpersonal communication to interact more appropriately and effectively. The social story approach provides the opportunity for people with ASD to identify the context, discuss their motives, comprehend the amplifiers or the obstacles, and improve their social skills [73][74].

6. An Examination of Acceptability, Usability, User Experience, Social Skills, and Executive Functions

The present study first aimed to assess the usability, user experience, and acceptability of immersive VR social skills training software (i.e., VRESS) in adults with ASD. The results showed that, in terms of the system's ratings, the VRESS software exhibited a relatively high performance with positive evaluations, as average scores were close to the high end of the possible scores on questionnaires. Secondly, the examination of the associations between mental state/emotion recognition, EFs, the functionality level of individuals with ASD, performance in VR social scenarios, and self-reported ratings revealed several statistically significant relations. Furthermore, the regression models' (single predictor) analyses revealed significant predictors of several aspects. The performance in VR social scenarios (i.e., the number of prompts required to effectively perform the social tasks) was the best significant predictor of the ASD functionality level, as well as the ratings of the VR system's perceived usability and VR social skills training acceptability. Inhibition speed (i.e., the response time in the Stroop task) was also a significant predictor of the ASD functionality level. Working memory (i.e.,

performance on the digit span forward task) was the second-best predictor of the ASD functionality level and a significant predictor of the VR system's perceived usability. Finally, the planning ability (i.e., performance on the Tower of London test) was the second-best predictor of the VR system's perceived usability and the best predictor of performance in VR social scenarios. Overall, the results of this study offer interesting insights into the utility and feasibility of VR social skills training in ASD, the possible implication of EFs in social skills, and the importance of social skills in ASD severity.

6.1. VR Training of Social Skills in Adults with ASD

Based on the authors of the SUTAQ, UXQ, and SUS recommendations for interpreting their scores for technological interventions' acceptability [75], the quality of the user experience facilitated by the software [76][77], and the system's usability [78], VRESS showed very high acceptability, user experience, and usability, as rated by participants with ASD. High acceptability suggests that this software [75], which also facilitates remote intervention and the training of social skills, will probably be preferred by adults with ASD. Likewise, the very high usability indicates that the VR software requires a small amount of effort from the user/trainee [78]. In VRESS, the user had only to speak to the 3D characters by using the microphone of the headset and navigate the virtual environment by pressing a single large button on the controller (either left or right). Hence, on the trainees' part, only a single button was required to be used, while the rest were controlled and operated by the researcher. Finally, the high user experience indicates that the VR software offered a highly pleasant and immersive experience to the trainee [76][77]. Given that providing a therapeutic process that is perceived as pleasant and positive by the patients enhances their engagement and commitment to therapy, as well as the effect size of the therapeutic outcomes [79], the high user experience of VRESS suggests that it may achieve comparable positive outcomes.

Furthermore, given that there is a scarcity of robust evidence supporting the feasibility and acceptability of implementing immersive VR interventions in populations with ASD [59][60][62], the results of this study provide substantial evidence that the implementation of immersive VR social skills training in ASD is feasible and acceptable by adults with ASD. However, it should be noted that VRESS was developed in line with the guidelines for developing VR software for psychological sciences [71]; these guidelines lead to VR software that meets the criteria of AACN and NAN [72]. For this reason, beyond the high ratings in terms of acceptability, user experience, and usability, the participants experienced minimal to absent symptoms of cybersickness, which indicates that VRESS is VR software that meets health and safety criteria. Finally, since VRESS was designed specifically for individuals with ASD, the observed high ratings of acceptability, user experience, and usability highlight the necessity of developing VR software that considers the highly prevalent cognitive and behavioural symptoms of ASD. However, a downside was that the usability and acceptability of VRESS were significantly predicted by the performance in social scenarios. This finding indicates that the negative feeling that was experienced when the participants performed negatively influenced them to rate VRESS with lower scores, while the positive feeling of accomplishment led to more positive scores. Both error correction and errorless learning have been seen as effective in ASD [80]; however, the results of this study suggest that an errorless approach in VR social skills training may result in even higher acceptability and perceived usability. Thus, instead of receiving prompts from the operator/researcher of VRESS, which may be perceived as external corrections, the VR system may provide in-game guidance to promote an errorless completion of social tasks while making the trainees feel that they completed them without external assistance (e.g., with the help of the researcher). Thus, an errorless approach should be preferred in a future iteration of VRESS.

6.2. Demographics' Role in Cognition

6.2.1. Executive Functions

The results showed that verbal working memory was correlated with the participants' education. The relationship between digit span scores and education is not surprising, considering that the majority of academic tasks involve reading and lectures, which rely heavily on verbal working memory. Working memory plays an important role in educational attainment, as it is consistently found to predict academic success [81][82]. Involved in the maintenance and processing of information [83], working memory is significantly associated with general reading, comprehension, and mathematical abilities [84][85][86]. In terms of inhibition, the Stroop response time was shown to be significantly associated with gaming experience ratings and usability. The findings of faster inhibition related to higher perceived usability scores could suggest that the ability to suppress automatic responses/ignore distractions more quickly allowed participants to better use and interact with the software. The significant association between gaming experience and the inhibition response time is in line with previous evidence showing that video gamers generally demonstrate faster reaction times and fewer errors relative to non-gamers [87]. Players of action video games were also found to have faster visual and auditory information processing; thus, they presented faster response times than non-gamers [88]. Indeed, practising tasks that rely on inhibition and working memory —such as video games—may lead to improved performance on similar tasks [89].

6.2.2. Mental State/Emotion Recognition

Mental state/emotion recognition ability was not found to be significantly related to performance in VR social scenarios but associated only with computing and gaming experience variables. Previous evidence suggests that individuals with ASD present difficulties in recognising mental states/emotions (e.g., [90][91][92]), but there are limited and mixed findings regarding its association with social competence (e.g., [26]). Generally, as already discussed in the Introduction, socio-cognitive abilities (such as the recognition of mental states/emotions) do not present consistent associations with social skills in ASD. The results show that, in adults with ASD, it is plausible that other cognitive functions (such as EFs) are more strongly implicated in the expression of social skills. Considering, though, that it could be the case that no single cognitive construct can explain all of the variance in social difficulties in ASD, further research is needed to shed more light on this association. Future studies may also take into consideration other emotional and relational factors that could potentially contribute to social skills. For example, individuals with ASD may have difficulty regulating their emotions (emotional regulation) or sharing others' feelings (e.g., empathy), which can make it challenging for them to respond appropriately to social cues and situations. Accordingly, low self-esteem, negative interpersonal relationships, or even low social motivation may also play a role in shaping the social skills of individuals with or without ASD. Finally, the correlations between mental state/emotion recognition, gaming experience, and computing experience reveal that individuals who had more experience with video games were more able to recognise mental states/emotions in the RTMIE test. Due to their interactive nature, modern video games offer realistic cinematics and compelling avatars with complex facial expressions, which may enhance gamers' ability to attribute and recognise emotions and mental states in real-life contexts.

6.3. Executive Functions and Social Skills

Gollwitzer's *implementation intention* pertains to the formulation of an effective plan of action, which incorporates the associations between a cue and the intended action (e.g., if I encounter X, then I will do Y) [93]. Correspondingly, planning ability is an executive function that requires thinking about the future and accordingly organising and prioritising future actions to achieve the desired goal(s) [15][94]. In everyday life, planning defines when and where an action will take place and involves updating/prioritising the plan of action based on acquired information (e.g., I received a notification for my overdue subscription to the gym, so I need to renew it this evening) [94]. As a result, impaired planning ability is highly prevalent in clinical populations with reduced everyday functionality [95][96], as well as in ASD [97][98]. In this study, planning ability was measured by the Tower of London test, which requires individuals to generate an explicit plan of action, including all the necessary steps, to achieve their goal [99]. Planning ability was found to be the best predictor of performance in VR social scenario performance (i.e., the number of prompts). Comparable to everyday life, the VR social scenarios required participants to plan/implement strategies for how to move their bodies, modulate the tone of their voices, express their thoughts and perspectives, and decide with which person they should approach and how they should interact with them to achieve the respective social goals (e.g., choosing a film and buying tickets for it). Participants with ASD who presented lower planning abilities experienced more difficulties in performing the required tasks in these social scenarios. On the other hand, participants with ASD who had better planning ability required fewer prompts to perform the social tasks in VRESS, suggesting that their planning ability assisted them in performing social interactions without requiring support. These results and interpretations are in line with the findings of studies in children with foetal alcohol spectrum disorders [95] and 22q11 deletion syndrome [96], where planning ability was a significant predictor of social skills. Note that, comparable to individuals with ASD [97][98], individuals with these syndromes frequently have impaired social skills and planning abilities [95][96]. Taken together with the results of this and previous studies, planning skills are likely to facilitate social interactions, as individuals need to plan and monitor their own and others' actions to adjust their responses and behaviours. Successful social interactions thus not only require the manipulation of one's and others' perspectives or the processing of social cues (i.e., working memory) but also may need planning abilities to make behavioural decisions and develop strategies. It should be noted at this point that social strategies may involve conscious planning, as discussed above, but of course, social behaviours may also manifest unconsciously (particularly in everyday life), as they are often based on previous interactions or emotional experiences.

In line with a review of studies on working memory impairments in ASD, where lower scores in verbal working memory were associated with greater problems in adaptive behaviour [100], in this study, verbal working memory was correlated with performance in VR social scenarios (i.e., the number of prompts). Performance in situations such as the social interactions presented in VRESS scenarios places high demands on processing, which in turn demands increased controlled attentional processing by the executive system of working memory. Participants with ASD who had higher digit span scores required fewer prompts to perform the social tasks in VRESS, suggesting that working memory may facilitate social interactions without individuals needing support and/or reminders. Cognitive structures such as the recognition and understanding of others' thoughts, beliefs, and mental/emotional states during social interactions place a heavier load on

working memory [101], as individuals have to actively maintain and manipulate personal perspectives and new, complex information from external social cues. Accordingly, social interactions could be considered a dual task (i.e., based on one having to balance personal perspectives with those of the people they are interacting with) and, for that reason, require working memory mechanisms [102]. Taking all these together, it is likely that participants with ASD who have lower working memory abilities required more prompts to complete the social scenarios because effective social cognition and social interaction are not possible unless one can effectively maintain and process perspectives, social cues, and communication strategies. Nevertheless, working memory ability was not a significant predictor of performance in VR social scenarios, suggesting that its implication in social skills may be secondary and/or moderating. Indeed, this interpretation of the findings agrees with the findings of a recent study, where a moderating role of working memory between verbal ability and social skills was observed during the early schooling years, during which the acquisition of social skills is crucial [103].

6.4. Predictors of Functionality Level in ASD

The results indicated that the ASD functionality level was related to and predicted by inhibition and verbal working memory, supporting previous evidence that has pinpointed a link between EFs and the severity of later features/symptoms in ASD [104]. Generally, impaired EFs have been proposed to underlie the severity of the core symptoms of the spectrum [100][105]. In line with this evidence, the results suggest that executive functions are central to ASD and highlight their importance as a crucial domain for support and training/intervention. It should be noted at this point, though, that less attention has been generally given to the examination of potential cognitive factors that may be crucial for the implementation of timely and effective interventions in ASD. Future longitudinal studies can further clarify whether executive functions have prognostic significance in adults with ASD.

Most importantly, though, the performance in VR social scenarios (i.e., number of prompts) was found to be the best significant predictor of the ASD functionality level. Impaired social and communication skills are core features of ASD, which is common across the spectrum regardless of the functionality level [106][107][108][109]. Although some of the best predictors of ASD severity/functionality in childhood are the language level [110] or IQ [111], the severity of social and communication skill impairments has been found to be associated with [106][109] or differ across [107][108] the diverse functionality levels within the ASD diagnosis. Observing the performance in VR social scenarios as a significant predictor of the ASD functionality level is thus aligned with the findings of the aforementioned studies. However, it should be noted that the results of this study indicated that social skills were not just a significant predictor but the best predictor of the functionality level in ASD. Given that the participants of this study were diagnosed with either functionality level 1 or 2 (i.e., high and moderate functioning, respectively) based on DSM-5 [1], this outcome suggests that social skills may potentially serve as a central indicating factor of functionality in high- and moderate-functioning adults with ASD. Notably, the social scenarios of VRESS benefit from enhanced ecological validity, which allows the depiction of everyday functionality [52][72]. Thus, this outcome may be also attributed to the enhanced ecological validity of VRESS social scenarios, which encompass the complexity and the demands of social contexts and situations in daily life.

6.5. Limitations and Future Studies

The findings of the present study should be interpreted considering its limitations. The present sample of adults with ASD may not represent the spectrum of the more general population. Participants' average age was approximately 30 years, being mostly representative of early adulthood (i.e., 20–39 years old). Future studies should thus establish whether these results can be replicated among younger children, adolescents, and/or older adults. Furthermore, the current study was not a randomised controlled trial (RCT) study to effectively examine the efficacy of VRESS in improving the social skills of individuals with ASD. Future studies should hence consider conducting an RCT experimental protocol, including the incorporation of a control group, to scrutinise the efficacy of VR interventions in enhancing the social skills of adults with ASD. Finally, VRESS did not offer an errorless learning approach, which the results showed may be beneficial for adults with ASD. Future iterations of VRESS should facilitate an errorless learning approach to improve its efficacy. Finally, future VR studies are needed to identify more potential prognostic markers of cognitive and social functioning in ASD.

7. Conclusions

VRESS appears to be an appropriate VR social skills training system that facilitates high acceptability, usability, and user experience in individuals with ASD, without inducing adverse symptoms. These positive outcomes pertaining to VRESS also support the effectiveness and feasibility of implementing VR social skills training in individuals with ASD. Furthermore, executive functions were found to be implicated in the social skills of adults with ASD. Finally, social skills were seen to be the best indicator of the severity/functionality level of adults with ASD.

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