



Apprentissage de scènes tactiques par imagination : Impacts de l'expertise et du moment du test

Hajer Mguidich

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**APPRENTISSAGE DE SCENES TACTIQUES PAR IMAGINATION :
IMPACTS DE L'EXPERTISE ET DU MOMENT DU TEST**

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**Apprentissage de Scènes Tactiques par Imagination : Impacts de
l'Expertise et du Moment du Test**

« Tu peux tout accomplir dans la vie si tu as le courage de le rêver, l'intelligence d'en faire un projet réaliste, et la volonté de voir ce projet mené à bien »

Sidney A. Fried

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Avis aux lecteurs

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Productions scientifiques

Mes travaux de recherche ont donné lieu aux publications suivantes :

Articles publiés :

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INTRODUCTION GÉNÉRALE

La performance supérieure des athlètes d'élite repose sur une combinaison de compétences multidimensionnelles, englobant non seulement des aspects physiques, mentaux, et techniques, mais également des compétences tactiques avancées (Devi, 2023 ; González-Víllora et al., 2015 ; Williams & Davids, 1995). Ces dernières s'avèrent particulièrement indispensables dans les sports d'invasion, tels que le basketball, où les athlètes doivent constamment coordonner leurs mouvements dans l'espace et dans le temps, tout en s'adaptant aux dynamiques changeantes du jeu. Leur objectif ? S'infiltrer avec efficacité dans le territoire adverse pour marquer ou atteindre un but précis (Duarte & Frias, 2011 ; Lord et al., 2020). Dans ce cadre, l'aptitude à analyser le jeu en direct devient un atout majeur. Les athlètes sont appelés à évaluer continuellement l'état du jeu actuel, repérer les opportunités d'avancer ou de marquer, tout en identifiant les menaces posées par les adversaires. Cette analyse va au-delà de la simple observation. Elle s'appuie sur la mobilisation de connaissances plus ou moins spécifiques – selon le niveau d'expertise de l'athlète – qui leur permettent d'identifier ou reconnaître les configurations de jeu afin d'y apporter des réponses adaptées (Shiffrin & Schneider, 1977). Avec le développement de leurs compétences tactiques, les joueurs améliorent leur capacité à évaluer finement le jeu, d'anticiper les évolutions en fonction du déroulement du jeu (North et al., 2011 ; Williams & Hodges, 2005, Williams et al., 2006), sélectionner les informations pertinentes et ignorer celles moins utiles (McPherson, 2008 ; Khacharem, 2017) et de prendre des décisions judicieuses – de type faut-il garder la balle, la passer ou tirer – (Causer & Williams, 2013 ; Craig & Watson, 2011 ; Gantois et al., 2020 ; Zoudji & Thon, 2003).

Pour optimiser la compréhension et l'assimilation des tactiques de jeu, les entraîneurs adoptent généralement deux approches complémentaires. D'une part, sur le terrain, l'accent est mis sur la mise en pratique de situations de jeu prototypiques à travers des exercices répétitifs et des simulations de match (ex, Gabbett et al., 2010 ; Memmert et al., 2015 ; Silva et al., 2016).

D'autre part, en dehors du terrain, notamment dans les vestiaires, la formation tactique repose sur la transmission par l'entraîneur d'instructions verbales – parfois accompagnées de supports visuels tels que des tableaux noirs ou des vidéos – afin de fournir aux joueurs les connaissances nécessaires pour les appliquer en jeu (Khacharem et al., 2020 ; Krause & Weigelt, 2022). Toutefois, malgré la fréquence de l'utilisation des instructions verbales, celles-ci ne garantissent pas toujours un apprentissage optimal. En effet, leur caractère abstrait ainsi que la nature passivement réceptive des apprenants dans les processus d'apprentissage et de traitement de l'information limitent leur efficacité (Kalyuga, 2012 ; Ben Chikha et al., 2023a). Récemment, plusieurs recherches ont démontré l'importance d'impliquer plus activement les apprenants dans leur processus d'apprentissage, en les incitant à interagir de manière dynamique avec les instructions verbales (Fiorella & Mayer, 2015a). Une stratégie prometteuse consiste à encourager les apprenants à imaginer le contenu et les instructions reçues, au lieu de les absorber de manière passive. Ce qu'on appelle « effet ou principe de l'imagination » (Cooper et al., 2001 ; Ignatova et al., 2020 ; Sweller et al., 2011) montre que lorsqu'ils mobilisent leur imagination, les apprenants s'engagent dans un traitement cognitif actif, ce qui peut faciliter la sélection des informations pertinentes, leur organisation mentale dans la mémoire de travail, ainsi que leur intégration avec les connaissances antérieures stockées dans la mémoire à long terme (théorie de l'apprentissage génératif ; Fiorella & Mayer, 2016). La Théorie de la Charge Cognitive (TCC : Sweller, 1988, 2020) explique également cet effet en supposant que les instructions d'imagination peuvent diriger explicitement les ressources cognitives disponibles de la mémoire de travail (qui sont les ressources pertinentes) vers l'ensemble des éléments en interaction (qui constituent la charge cognitive intrinsèque), ce qui facilite par conséquent leur transfert vers la mémoire à long terme.

Cependant, la recherche montre que l'efficacité des stratégies d'apprentissage peut être influencée par plusieurs facteurs, notamment les connaissances antérieures et le moment du

test. L'importance des connaissances préexistantes est soulignée par l'effet de renversement de l'expertise (Kalyuga, 2007 ; Kalyuga et al., 2003; Khacharem et al., 2013a), selon lequel des stratégies pédagogiques qui sont bénéfiques pour les novices peuvent s'avérer inefficaces, voire préjudiciables pour les experts, et vice versa. De plus, le moment du test joue un rôle crucial. Le concept de difficultés désirables (Bjork & Bjork, 2011) révèle que, bien que certaines stratégies exigeant un effort mental conséquent puissent sembler inefficaces lors d'un test immédiat, elles peuvent significativement améliorer les performances lors d'un test réalisé ultérieurement.

Cette thèse se consacre principalement sur l'analyse de l'impact de l'imagination dans l'apprentissage des systèmes tactiques dans le basket-ball. Bien que la validité de cet effet ait été largement identifié dans divers contextes d'apprentissage académiques et pédagogiques (Cheng & Beal, 2019 ; Leopold & Mayer, 2015 ; Lin et al., 2017), son rôle dans l'acquisition et l'intégration de connaissances sportives – plus particulièrement tactiques, reste à explorer. Ce travail explore également les variations de l'effet d'imagination en fonction du moment du test (immédiat ou différé) et du niveau d'expertise des joueurs (novices ou experts). Pour évaluer ces aspects, des mesures objectives (ex, test de rappel-reconstruction ; Chase & Simon (1973)), ainsi que des mesures subjectives des différentes sources de charges cognitives mobilisées durant l'interaction avec la tâche d'apprentissage (Paas, 1992 ; Cierniak et al., 2009), ont été utilisées.

Ce document est structuré en 6 chapitres visant à explorer en détail les différentes questions abordées dans cette thèse. Le **Chapitre 1**, basé sur une revue de littérature, analyse d'abord les caractéristiques essentielles de l'imagerie mentale et leurs implications dans l'apprentissage. Il présente ensuite la Théorie de la Charge Cognitive (qui représente la base de nos travaux), en se concentrant sur l'architecture cognitive humaine et les sources de la charge cognitive associées à l'apprentissage. Enfin, il explore les facteurs influençant l'apprentissage,

en mettant l'accent sur l'effet de renversement de l'expertise et le concept des difficultés désirables. Le **Chapitre 2** propose une méta-analyse et une revue systématique destinées à évaluer précisément l'efficacité de l'imagination comme stratégie d'apprentissage et à identifier les facteurs modérateurs qui pourraient influencer sur cette efficacité. Le **Chapitre 3** qui constitue le pilier de nos travaux, examine les effets de l'imagination et de l'expertise sur les performances d'apprentissage tactique et la réduction de la charge cognitive. Les chapitres suivants détaillent l'efficacité de différents facteurs : le timing de présentation des scripts, qu'ils soient présentés simultanément à l'instruction ou de manière séquentielle (**Chapitre 4**) ; l'intégration des gestes de traçage à l'imagerie mentale (**Chapitre 5**) ; et la modalité de présentation des scripts, audio ou écrit (**Chapitre 6**), sur l'apprentissage des instructions tactiques transmises par l'entraîneur.

PARTIE THÉORIQUE

Chapitre 1 : Revue de littérature

Utilisation de l'imagerie dans le domaine du sport

L'imagerie mentale : qu'est-ce que c'est et comment fonctionne-t-elle ?

L'imagerie mentale est considérée comme une des méthodes de préparation mentale les plus populaires et les plus fréquemment utilisées par les athlètes (Cumming & Williams, 2012 ; Morris et al., 2004). Cette technique repose sur une forme de simulation très élaborée qui imite les expériences sensorielles vécues lors d'activités réelles, bien que ces expériences soient intégralement générées et vécues mentalement (Simonsmeier et al., 2021 ; Vealey & Greenleaf, 2010). À la différence de la visualisation mentale, qui se limite uniquement à l'aspect visuel (comme se voir réaliser un mouvement spécifique), l'imagerie mentale engage tous les sens, permettant ainsi une immersion totale et une reproduction précise de l'expérience projetée. Par conséquent, l'image mentale générée peut être non seulement visuelle, mais également kinesthésique (imaginer les sensations associées à des actions telles que l'impulsion ou la réception), auditive (se représenter des sons spécifiques, tels que le bruit d'une balle frappée), olfactive (sentir l'odeur du gazon fraîchement coupé) et gustative (goûter la sueur sur sa langue durant un effort intense). Lorsqu'elle est appliquée efficacement, l'imagerie mentale peut améliorer considérablement l'apprentissage et la performance. Son impact se manifeste de deux manières : directement par le perfectionnement des compétences motrices et des tactiques, et indirectement, en contribuant à l'atteinte d'un état psychologique optimal, comme le développement de la confiance en soi et la régulation de l'anxiété (Cumming & Williams, 2013 pour une revue).

L'étude de l'efficacité de l'imagerie mentale repose sur des données robustes issues de la neurosciences et de la psychologie. Le principe de l'équivalence fonctionnelle, par exemple, offre une perspective neuropsychologique en suggérant que l'imagerie mentale et les processus

cognitifs partagent des caractéristiques similaires, ce qui signifie que les processus cérébraux activés durant l'imagerie sont analogues à ceux mis en œuvre lors de l'exécution physique d'actions (Finke, 1980 ; Jeannerod, 1995). Cette co-activation cérébrale est censée faciliter la réalisation de mouvements et améliorer les performances par un renforcement neuronal (Kosslyn et al., 2001). D'autre part, la théorie de l'apprentissage symbolique (Sackett, 1934) avance que l'imagerie mentale fonctionne comme un système de codage aidant à comprendre et maîtriser des modèles de mouvement. Apprendre une compétence implique donc souvent de se familiariser avec les étapes nécessaires à sa réalisation réussie. Lorsqu'un individu développe un programme moteur dans son système nerveux central, il crée également un schéma mental qui facilite une exécution fluide et automatique du mouvement sur le long terme (Martin et al., 1999). Enfin la théorie bio-informationnelle de Lang (1977, 1979), postule que les images mentales sont structurées en trois propositions fonctionnellement organisées et stockées en mémoire à long terme : la proposition de stimulus décrit le contenu du scénario à imaginer et dépend de l'environnement où le mouvement est exécuté ; la proposition de réponse détaille les réactions de l'individu –psychologiques que physiologiques – suite à ce scénario ; et la proposition de signification concerne les implications et la signification personnelle de l'image pour l'individu.

Le Modèle 2×2 de l'imagerie mentale

Au-delà des cadres théoriques relatifs à l'imagerie mentale, de nombreux témoignages d'athlètes mettent en lumière les avantages considérables de cette technique. Ils rapportent que l'imagerie mentale est cruciale pour le perfectionnement des compétences motrices et pour l'acquisition de schémas cognitifs complexes, tels que les tactiques et stratégies de jeu (Callow et al., 2001 ; Cumming & Ste-Marie, 2001; Martin & Hall, 1995; Martin et al., 1999; Morris et al., 2005; Munroe-Chandler et al., 2012). Paivio (1985) a développé un modèle 2×2 pour examiner les fonctions cognitives et motivationnelles de l'imagerie mentale, avec une

subdivision de chaque dimension en niveaux général et spécifique. L'imagerie cognitive générale (CG) est destinée à améliorer les stratégies et les plans d'action, tandis que l'imagerie cognitive spécifique (CS) vise à affiner des compétences motrices particulières. Parallèlement, l'imagerie motivationnelle générale (MG) intègre des images de maîtrise et d'excitation, tandis que l'imagerie motivationnelle spécifique (MS) aide à atteindre des objectifs précis. Plus tard, Hall et al. (1998) ont proposé une extension du modèle de Paivio en subdivisant l'imagerie MG en MG-arousal (MG-A, qui renforce la confiance et les sentiments de compétence) et MG-éveil (MG-E, qui régule les sentiments et les émotions) (Figure 1).

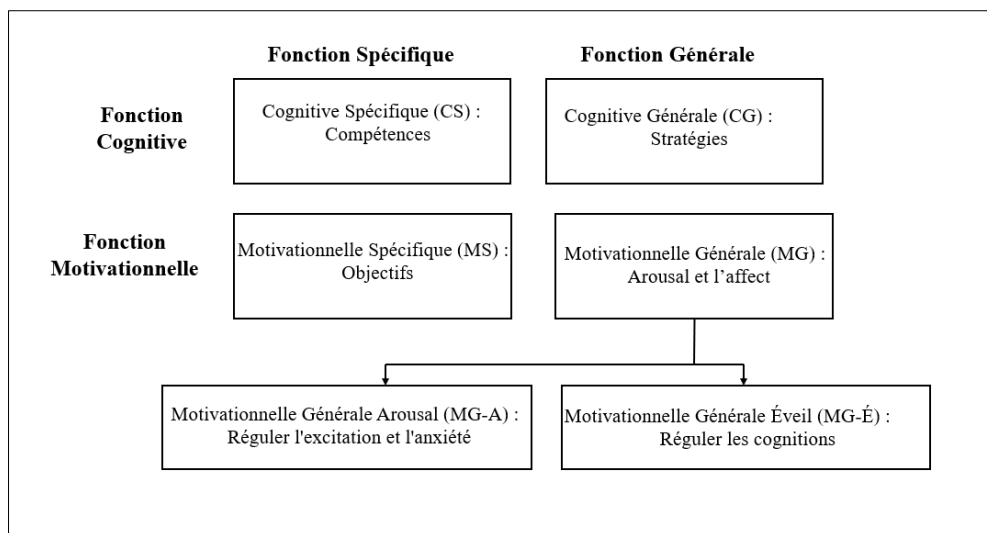


Figure 1. Modèle 2×2 de Paivio (1985) complété par Hall et al. (1998)

L'imagerie CG

L'imagerie CG est fréquemment utilisée pour optimiser les stratégies de jeu dans une variété de disciplines sportives, notamment les courses de slalom en canoë, le ski, le football, la lutte, et le basketball (pour une revue exhaustive, voir Martin et al., 1999 ; Paivio, 1985, Westlund et al., 2012). Dans une étude récente, Frank et al. (2018) ont analysé les effets d'un programme d'imagerie d'action d'équipe sur une période de 4 semaines, visant à améliorer les représentations mentales des tactiques d'équipe chez les joueurs de futsal. Les participants ont été répartis soit dans un groupe d'entraînement par imagerie, soit dans un groupe témoin sans entraînement

spécifique par imagerie. Dans le groupe d'entraînement par imagerie, les joueurs ont répété quatre tactiques d'équipe en imaginant des actions spécifiques dans des scénarios de jeu trois fois par semaine (Figure 2). Les résultats ont révélé que les représentations mentales des tactiques d'équipe étaient significativement améliorées dans le groupe ayant suivi l'entraînement par imagerie, les rapprochant davantage de celles des experts par rapport au groupe témoin. Ces conclusions soulignent l'impact positif de l'entraînement par imagerie sur le développement des compétences tactiques et leur intégration dans la mémoire à long terme des joueurs de futsal.



Figure 2. Capture d'écran d'un script d'imagerie pour la représentation mentale des actions interpersonnellement coordonnées entre les joueurs d'une équipe, tirée de l'étude de Frank et al. (2018)

De même, une étude menée par Stewart et Hall (2016) a examiné l'effet d'une intervention d'imagerie CG de 6 semaines sur la précision et la rapidité de la prise de décision des curleurs universitaires dans des situations de jeux. Le sport du curling a été ciblé et un outil d'évaluation stratégique a été développé pour évaluer spécifiquement la capacité stratégique du curling. Les résultats ont montré que les temps de réponse des curleurs à une évaluation informatisée de la stratégie de curling se sont considérablement améliorés entre le début et la post-intervention. Les chercheurs ont conclu que l'entraînement en imagerie CG peut effectivement augmenter la performance stratégique des joueurs de curling, renforçant ainsi

leur aptitude à déployer diverses stratégies en situation de jeu. En revanche, Munroe Chandler et al. (2005) ont cherché à déterminer l'efficacité d'une intervention de 6 semaines d'imagerie CG sur trois stratégies de football distincts au sein d'une jeune équipe féminine de football d'élite. Ils ont utilisé un plan d'étude en plusieurs phases pour évaluer l'impact de l'imagerie sur trois stratégies spécifiques : (i) défendre un coup franc direct, (ii) tirer un coup franc direct, et (iii) défendre un coup de pied de coin. Ces dernières ont été introduites respectivement aux semaines 2, 4 et 6. Les résultats ont montré que l'exécution des stratégies de football n'a pas été significativement améliorée avec la mise en œuvre d'une intervention en imagerie mentale. Les résultats mitigés de ces études peuvent être attribués aux défis liés à la mesure de la performance stratégique, étant donné que les stratégies varient d'un sport à l'autre et que leur exécution dans des conditions réelles peut être difficile à contrôler, compliquant ainsi le processus de mesure (Westlund Stewart et al., 2012). De plus, l'utilisation de l'analyse de groupe, qui néglige les schémas individuels et les comportements cruciaux pour évaluer les progrès des athlètes dans des contextes réels, peut contribuer aux résultats mitigés (c'est-à-dire, l'effet de masquage, Bryan, 1987 ; Shambrook & Bull, 1996).

L'imagerie dynamique

La recherche sur l'imagerie mentale s'est traditionnellement concentrée sur ce que l'on appelle l'imagerie statique, où les participants visualisent mentalement des scénarios spécifiques sans mouvement physique (Robin et al., 2007). Toutefois, des avancées récentes ont élargi ce champ d'étude en combinant l'imagerie mentale avec de légers mouvements physiques, comme des gestes subtils des mains ou des bras, tout en imaginant l'exécution de tâches précises. Cette méthode innovante, appelée « imagerie dynamique », offre de nouvelles possibilités pour étudier et améliorer l'efficacité de l'imagerie mentale dans le contexte de l'entraînement et de la performance (Guillot et al., 2013 ; 2021). Dans une recherche menée par Callow et al. (2006), des skieurs alpins ont été encouragés à intégrer de légères oscillations de

la main ou du bras à leur pratique d'imagerie mentale, tout en visualisant leur descente en slalom. Les résultats ont révélé des différences notables entre les groupes : ceux qui ont pratiqué l'imagerie dynamique ont rapporté des visualisations plus vivantes et ont également montré une amélioration significative de leurs performances en slalom comparativement au groupe ayant utilisé l'imagerie statique. Dans une autre étude, Guillot et al. (2013) ont examiné les effets de l'imagerie dynamique chez des athlètes spécialisés en saut en hauteur. Plus spécifiquement, ils ont examiné l'impact de l'intégration de mouvements de bras dans l'imagerie motrice sur la performance des sauts (voir Figure 3). Les résultats ont révélé que l'imagerie dynamique améliorait significativement la synchronisation temporelle entre l'imagerie et l'exécution physique des sauts. De plus, cette pratique a eu un impact positif sur la technique de saut, conduisant à des tentatives plus réussies. En outre, les participants ont rapportés une amélioration significative dans la capacité à former des images mentales claires et précises de leurs mouvements. Dans une étude plus récente sur le lancer franc au basket-ball menée par Kanthack et al. (2016), les chercheurs ont observé que l'intégration de l'imagerie dynamique avec des séances d'entraînement physique améliorait significativement la précision des tirs chez les athlètes de haut niveau. De plus, cette approche s'est révélée plus efficace que la seule pratique d'imagerie statique associée à des séances d'entraînement physique, ainsi que par rapport à la pratique physique seule.



Figure 3. Capture d'écran illustrant l'imagerie statique (A) et l'imagerie dynamique (B). Tiré de l'étude de Guillot et al. (2013)

Processus cognitifs impliqués dans l'apprentissage

La théorie de la charge cognitive

La Théorie de la Charge Cognitive (TCC) est une théorie pédagogique fondée sur notre connaissance de la cognition humaine (Sweller et al., 2011). Développée par John Sweller à la fin des années 1980 suite à une étude sur la résolution de problèmes, cette théorie s'appuie sur les composantes de l'architecture cognitive humaine pour produire des effets pédagogiques (tels que l'effet de l'imagination ; Cooper et al., 2001). Ces effets aident les apprenants à acquérir d'importantes quantités de connaissances spécifiques à un domaine et à faciliter leur transfert vers la mémoire à long terme (Tricot & Sweller, 2014).

L'architecture cognitive humaine

Selon la TCC, l'architecture cognitive humaine est composée de deux structures indispensables pour l'apprentissage : la Mémoire de Travail (MdT) et la Mémoire à Long Terme (MLT). La **MdT** est « ...un système cérébral qui assure le stockage temporaire et la manipulation des informations nécessaires à des tâches cognitives aussi complexes que la compréhension, l'apprentissage et le raisonnement » (Baddeley, 1992 ; p.556). Elle est caractérisée par sa capacité limitée, pouvant traiter un nombre restreint d'informations nouvelles (7 ± 2 éléments selon Miller, 1956 ; 4 ± 1 éléments selon Cowan, 2001, 2010). De plus, sa durée de rétention est également limitée à environ 20 secondes (Barrouillet & Camos, 2007). Baddeley et Hitch (1974) ont identifié trois sous-composantes de la MdT : l'administrateur central (ou centre exécutif), qui supervise et régule les processus cognitifs et le flux d'informations vers et depuis ses deux systèmes esclaves; le calepin visuo-spatial, qui gère les images visuelles et spatiales et peut intégrer des composantes visuelles, spatiales, et éventuellement kinesthésiques; et la boucle phonologique, essentielle pour le stockage et la répétition des informations verbales, jouant un rôle vital dans l'acquisition du langage. En 2000,

Baddeley a étendu ce modèle en ajoutant le « *buffer épisodique* », une quatrième composante, pour aborder le manque de consensus concernant la relation entre la MdT et la MLT (voir figure 4). Le buffer épisodique est un système de stockage temporaire à capacité limitée, contrôlé par l'administrateur central, capable de combiner des informations provenant de la MLT, du calepin visuo-spatial ou de la boucle phonologique, jouant ainsi un rôle vital dans la coordination des informations entre la MLT et les autres sous-composantes de la MdT

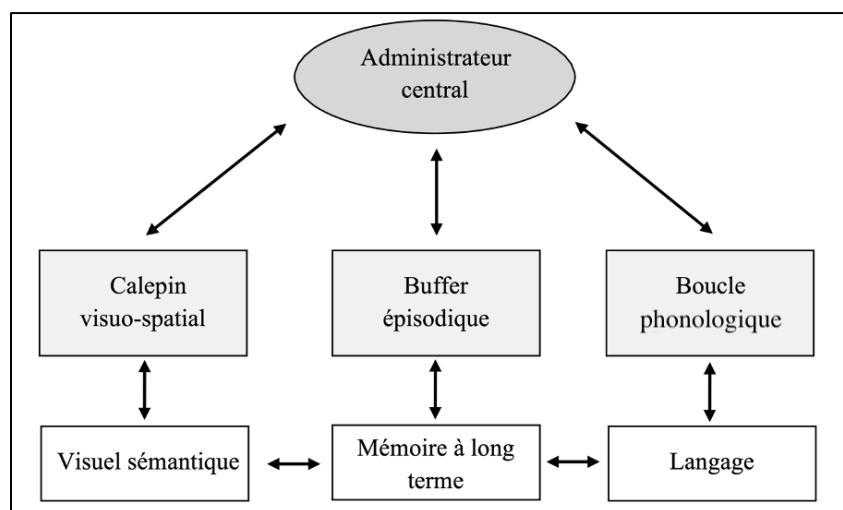


Figure 4. Modèle de la Mémoire de Travail (MdT : Baddeley, 2000, 2003)

La **MLT** est la deuxième composante majeure de l'architecture cognitive humaine. Elle peut être définie comme le dépôt des connaissances et des compétences qui ne sont pas actuellement conservées dans la MdT (Bower, 1975). Contrairement à la MdT, la MLT présente une capacité et une durée de stockage quasi illimitée pour les informations une fois qu'elles sont acquises. Elle constitue une vaste base de connaissances où les informations sont stockées sous forme de schémas¹, présentant différents niveaux de complexité et d'automatisme (Sweller et al., 1998, Sweller, 2010). Ces schémas aident à surmonter les contraintes du système cognitif en regroupant plusieurs éléments d'information dans des structures de haut

¹ Un schéma est défini comme un ensemble de connaissances organisées, autonomes et récupérées comme telles en mémoire à long-terme (Minsky, 1975).

niveau, qui sont alors traitées comme des unités simples par la MdT (Sweller & Cooper, 1985). Cette structuration facilite la gestion de l'information et favorise la récupération des connaissances en cas de besoin. En construisant des schémas de complexité croissante, la performance cognitive s'améliore, intégrant des éléments de niveau inférieur pour élaborer des schémas de niveau supérieur (Chi et al., 1981). Un schéma peut incorporer une énorme quantité d'informations et devenir automatisé après un apprentissage prolongé (Ericsson & Charness, 1994 ; Simon & Gilmarin, 1973). Une fois automatisés, ces schémas ne nécessitent plus de traitement actif dans la MdT, réduisant ainsi la charge cognitive et libérant des ressources pour d'autres processus cognitifs (Van Merriënboer & Sweller, 2005). L'exécution d'une tâche sans bénéficier d'un schéma automatisé peut se révéler moins efficace et moins précise comparativement à une performance automatisée. En termes cognitifs, les schémas mentaux (cognitifs) servent de guide interne qui facilitent la performance en simplifiant le processus d'encodage des instructions (Sweller, 2003). Ainsi, lorsqu'un individu acquiert de l'expertise dans un domaine, il reconnaît les situations comme familières et typiques : il active alors, récupère et met en œuvre la structure cognitive correspondante pour gérer efficacement le flux d'informations entrantes (Kalyuga & Sweller, 2005).

Implications pour l'expertise

L'expertise repose principalement sur l'acquisition et le développement de connaissances stockées sous formes de schémas dans la MLT (Paas & van Merriënboer, 2020). Les recherches portant sur la notion de l'expertise au jeu d'échecs ont permis de mettre en lumière cette relation cruciale (Chase & Simon 1973 ; De Groot, 1946 ; 1966). De Groot (1960) a présenté aux maîtres de jeu d'échecs et aux joueurs occasionnels une configuration de plateau issue d'une partie réelle, qu'ils devaient mémoriser puis reproduire après sa disparition au bout de cinq secondes. Les maîtres ont montré une précision d'environ 70 %, tandis que les joueurs occasionnels étaient autour de 30 %. Une étude ultérieure de Chase et Simon (1973) a confirmé

ces résultats, mais a aussi révélé que lorsque les configurations étaient aléatoires et non issues de parties réelles, tant les maîtres que les joueurs occasionnels montraient une précision similaire % (environ 30 %). Ces observations suggèrent que l'avantage des joueurs experts est spécifiquement lié à leur capacité de mémorisation des configurations issues de situations de jeu réelles, plutôt qu'à l'application de stratégies générales de résolution de problèmes. Par ailleurs, ces résultats ont été reproduit dans divers autres domaines comme le basketball (Allard et al., 1980 ; Khacharem, 2017 ; Gil-Arias et al., 2019), la danse (Starkes et al., 1987), le volleyball (Conejero Suárez et al., 2020 ; Bourgeaud & Abernethy, 1987 ; Lola et al., 2021), le hockey sur glace (ex, Starkers & Deakin, 1984), ou encore le football (Breed et al., 2018 ; Glavas et al., 2023 ; Williams et al., 1993 ; Williams & Davids, 1995).

Dans une étude classique, Allard et al. (1980) ont comparé les performances de joueurs de basketball experts et novices lors d'une tâche de rappel impliquant des situations schématiques, à la fois structurées et non structurées (c'est-à-dire avec des joueurs positionnés aléatoirement sur le terrain). Ils ont découvert que les joueurs experts rappelaient les positions des joueurs avec plus de précision que les novices, mais seulement dans les situations structurées. Les résultats de ces études indiquent que les joueurs novices éprouvent souvent des difficultés à encoder et à reconnaître des schéma complexe en raison de limitations dans leur MdT et d'un niveau de connaissances de base moins développé (Gobet & Simon, 1996, 1998). En revanche, les joueurs experts ont la capacité de stocker dans leur MLT des schémas cognitifs qui représentent des modèles de jeu familiers, ce qui facilite leur capacité à se souvenir précisément des emplacements sur le terrain, comme la position des joueurs et du ballon. Selon le concept de la mémoire de travail à long terme (Ericsson & Kinsth, 1995), les experts peuvent mobiliser des structures de connaissances pertinentes stockées dans leur MLT comme des schémas de récupération et les traiter comme des unités d'information uniques dans leur MdT. Cette approche leur permet d'étendre considérablement la capacité effective de leur MdT.

(Guida et al., 2009), surtout dans des contextes relevant de leur domaine d'expertise. Ces schémas de récupération (également appelés schémas cognitifs dans le contexte de la TCC), représentent des connaissances abstraites et hiérarchisées, où les informations codées sont associées à des indices de récupération. Il est suggéré que ces schémas de récupération permettent aux experts de d'intégrer plus rapidement les nouvelles informations dans leur MLT et de les récupérer efficacement en cas de besoin. Par ailleurs, à mesure que les apprenants deviennent plus expérimentés dans un domaine, leurs schémas cognitifs se développent et le traitement devient de plus en plus automatisé, entraînant ainsi une réduction de la charge de la MdT. Selon Anderson et al. (1997), les experts peuvent automatiquement accéder à des connaissances spécifiques en MLT en convertissant les connaissances déclaratives, qui exigent une activation consciente et contrôlée, en connaissances procédurales ne nécessitant pas de traitement conscient et peu coûteux en ressources attentionnelles. Cette automatisation dans l'accès à ces connaissances spécifiques permet de surmonter les limitations de la capacité de la MdT en libérant les ressources attentionnelles requises pour accomplir d'autres tâches complexes (Cooper & Sweller, 1987 ; Kalyuga et al., 2012). En revanche, les débutants ou novices manquent de ces connaissances procédurales automatisées et doivent s'appuyer plus intensivement sur leur MdT lorsqu'ils traitent de nouvelles informations. Ce recours accru à la MdT pour gérer des connaissances (non encore automatisées) crée une charge cognitive plus importante, ce qui peut réduire l'efficacité et la rapidité de l'apprentissage. Il est important de noter que la construction et l'automatisation des schémas cognitifs en mémoire MLT ne dépendent pas tant de la quantité d'expérience, comme le suggèrent les règles de 10 ans de pratique (Simon & Chase, 1973) ou des 10,000 heures de pratique (Ericsson et Polson, 1988), mais plutôt de l'engagement dans des efforts délibérés et ciblés visant à améliorer les performances (VanGog et al., 2005). Cette idée est en accord avec la théorie de la pratique délibérée Ericsson et al. (1993) qui suggère que c'est l'intensité de l'investissement dans des

pratiques spécialement conçues pour le développement de compétences qui distingue les experts des novices. Les activités constituant la pratique délibérée sont donc adaptées pour être suffisamment difficiles afin de stimuler le progrès, permettant ainsi une amélioration progressive grâce à la répétition, la correction d'erreurs, et un retour d'information continu et adaptatif. L'entraînement délibéré, par nature, exige une concentration intense et est difficile à soutenir sur de longues périodes ; il n'est pas nécessairement plaisant en soi, mais est poursuivi pour ses effets bénéfiques sur la performance (Ericsson & Lehmann, 1999 ; Ericsson, 2020 ; Ericsson & Harwell, 2019).

Types et mesures de la charge cognitives

La charge cognitive imposée à la MdT peut être catégorisée selon sa nature et son impact sur l'apprentissage (Sweller, 1988 ; Sweller et al., 1998 ; Sweller et al., 2020). À cet égard, deux types de charges cognitives sont distinguées : la charge cognitive extrinsèque, également appelée charge inutile (*extraneous load*) et la charge cognitive intrinsèque (*intrinsic load*).

La charge cognitive intrinsèque est décrite comme la charge causée par la complexité interne du matériel d'apprentissage, qui est mesurée par le degré d'interconnexion entre les éléments essentiels de l'information qui doivent être traités simultanément dans la MdT (c-à-d, l'interactivité des éléments) (Sweller, 1994). Par conséquent, un matériel qui contient un grand nombre d'éléments fortement interactifs est considéré comme plus complexe et donc plus difficile à apprendre que celui avec moins d'éléments et/ou une interactivité moindre. Le matériel à faible interactivité comprend des éléments simples et distincts qui peuvent être appris isolément, tandis que dans le matériel à forte interactivité, la compréhension de chaque élément dépend de sa relation avec les autres (Sweller 1994 ; Sweller et al. 1998). La charge cognitive intrinsèque est également influencée par les connaissances préalables de l'apprenant. L'apprentissage consiste à former des schémas cognitifs, chacun de ces schémas pouvant être

traité en MdT comme une unité d'information distincte. Ainsi, le même contenu d'apprentissage impose moins de charge cognitive intrinsèque pour les apprenants possédant un niveau de connaissances préalable plus élevé, par rapport à ceux ayant des connaissances plus limitées ou aucun acquis (Sweller et al., 1998). Dans des situations où la charge cognitive intrinsèque est extrêmement élevée, la quantité et la complexité des informations à maintenir et à manipuler en MdT peuvent être tellement importants qu'il devient impossible de consacrer suffisamment de temps à leur rétention et à leur traitement complet. La TCC préconise ainsi une optimisation de la charge cognitive intrinsèque des matériaux d'apprentissage, avec un niveau de difficulté pour qu'il soit stimulant, mais pas excessif (Schnotz & Kürschner, 2007 ; Sweller, 2010).

La charge cognitive extrinsèque, également qualifiée de charge inutile fait référence à la charge cognitive générée par la manière dont l'information est présentée dans les supports pédagogiques utilisés, ainsi que par des méthodes d'enseignement inappropriées qui peuvent perturber l'apprentissage (Chandler & Sweller, 1991). Ce type de charge est considéré comme superflu car il s'ajoute à la charge cognitive intrinsèque du matériel sans être essentiel au processus d'apprentissage (Chanquoy et al., 2007). La charge extrinsèque est déterminée par la manière dont les informations sont organisées et présentées aux apprenants. Une présentation plus claire et bien structurée des informations permet de réduire cette charge cognitive extrinsèque, tandis qu'une présentation mal conçue peut entraver l'apprentissage en augmentant cette charge, contraignant ainsi l'apprenant à consacrer des ressources cognitives à traiter les informations non pertinentes. Par conséquent, la conception pédagogique efficace est cruciale : elle vise à minimiser la charge cognitive extrinsèque en structurant et en présentant l'information de manière à optimiser l'apprentissage et la compréhension.

D'après la TCC, les charges cognitives intrinsèques et extrinsèques sont additives (Sweller et al., 2011). De ce fait, il est essentiel de planifier les activités d'apprentissage de manière à optimiser l'utilisation de la capacité de la MdT, dans le but de maximiser l'efficacité

de l'effort mental déployé. Cela implique la nécessité de réduire au minimum la charge cognitive inutile pour libérer de la capacité dans la MdT. Ce processus permet ainsi une allocation accrue des ressources de travail vers la charge cognitive intrinsèque – également qualifiée de **ressources cognitives pertinentes** (Choi et al, 2014) – c'est-à-dire vers les aspects du matériel d'apprentissage directement liés à l'apprentissage. Ce concept de ressources cognitives pertinentes remplace l'ancien élément de charge cognitive pertinente (*germane load*) dans le modèle tri-factoriel du CLT (Sweller et al., 1998), introduisant l'idée d'une charge cognitive distincte liée à la construction et l'automatisation des connaissances en MLT. La charge cognitive pertinentes est désormais considérée comme une ressource pertinente qui reflète la quantité de capacité de MdT spécifiquement dédiée à l'apprentissage et à la construction de schémas cognitifs.

Au cours des dernières décennies, mesurer la charge cognitive pendant le processus d'apprentissage est devenue un enjeu crucial (Brünken et al., 2010 ; Schnotz & Kürschner, 2007 ; Moreno, 2010). Initialement, cette mesure s'effectuait principalement par des interrogations des apprenants sur l'effort mental investi, une méthode introduite par Paas (1992) et largement utilisée dans les études sur la charge cognitive. Toutefois, cette approche présente des limitations, notamment l'incapacité à distinguer entre les différentes sources de charge cognitive définies par la TCC, ce qui réduit son utilité dans la conception pédagogique et la recherche en apprentissage multimédia. Pour surmonter ces défis, Cierniak et ses collègues (2009) ainsi que Cierniak (2011) ont développé une méthode utilisant les trois éléments distincts pour mesurer la charge intrinsèque, la charge extrinsèque et la charge germane. Leurs études ont révélé des corrélations significatives entre les performances des participants et les différentes charges cognitives mesurées. Pour ce faire, ils ont employé des indicateurs tels que l'« effort mental investi » (adaptée de Paas, 1992) pour mesurer la charge intrinsèque, la « difficulté d'apprentissage avec le matériel » (adaptée de Kalyuga et al., 1998) pour

représenter la charge extrinsèque et « la concentration pendant l'apprentissage » (adaptée de Salomon, 1984) pour représenter la charge pertinente.

Le principe de l'imagination

L'effet d'imagination est un principe de la TCC qui se produit lorsque les apprenants qui sont invités à « imaginer » une procédure ou un concept présentent de meilleures performances et un apprentissage supérieur par rapport à ceux qui étudient de manière passive le même contenu (Cooper et al., 2001 ; Ginns, 2005 ; Leahy & Sweller, 2008 ; Ignatova et al., 2020). Plusieurs recherches expérimentales ont confirmé les avantages de l'utilisation de l'imagination, mesurés en termes de scores de rétention, de transfert, de rappel, de compréhension et d'apprentissage, et ce, pour différents groupes d'âge (tels que des enfants et des adultes), ainsi que dans divers domaines académiques comme les mathématiques (Leahy & Sweller, 2004, 2005), la physiologie (Leopold & Mayer 2015, Leutner et al., 2009), l'informatique (Cooper et al., 2001), et l'apprentissage des langues (Ignatova et al., 2020). La recherche sur l'effet de l'imagination dans le contexte de la TCC a débuté avec une étude de Cooper et al. (2001), qui a exploré l'efficacité des instructions d'imagination dans la construction de formules sur tableur. Deux groupes d'étudiants ont été confrontés à deux conditions différentes : l'un consistait à imaginer les étapes de performance associées à l'utilisation d'un tableur informatique après avoir étudié un exemple travaillé (condition d'imagination), tandis que l'autre groupe se contentait à étudier l'exemple travaillé (condition d'étude). Les résultats ont montré que les étudiants de la condition imagination obtenaient des scores significativement plus élevés aux tests. Dans une autre étude, Leutner et al. (2009) ont demandé à des lycéens de lire un texte de 1 600 mots sur les molécules d'eau, divisé en 13 paragraphes, et d'imaginer le contenu de chaque paragraphe (groupe d'imagination) ou d'étudier chaque paragraphe (groupe de contrôle). Lors d'un test de compréhension ultérieur, le groupe d'imagination a obtenu des résultats nettement supérieurs à ceux du groupe contrôle, ce qui indique que l'imagination peut améliorer la

compréhension d'un texte scientifique. Dans une autre étude, Leopold & Mayer (2015) a exploré l'efficacité de l'emploi de l'imagination dans l'apprentissage d'un texte scientifiques (divisé en 9 paragraphes) portant sur le fonctionnement du système respiratoire humain. Le premier groupe devait imaginer une illustration pour chaque paragraphe lu (groupe d'imagination), tandis que le second groupe lisait le texte de manière normale (groupe d'étude). Les résultats ont montré que le groupe « imagination » surpassait le groupe d'étude dans les tests de rétention.

Tableau 1. Les trois processus cognitifs activés par l'imagination (Fiorella & Mayer, 2015a)

Processus cognitif	Description de chaque processus
Sélection	Les apprenants choisissent les éléments à intégrer dans leur image.
Organisation	Les apprenants organisent mentalement les éléments dans une disposition spatiale.
Intégration	Les apprenants passent d'un mode de représentation à un autre, par exemple des mots aux images, ce qui nécessite de relier les informations entrantes aux connaissances activées dans la MLT.

LA TCC stipule que les instructions d'imagination canalisent explicitement les ressources cognitives de la MdT vers les éléments interactifs, facilitant ainsi leur transfert vers la MLT, ce qui facilite l'apprentissage. Ce processus exploite efficacement la capacité limitée de la MdT en concentrant l'attention et les efforts cognitifs sur des éléments clés du contenu à apprendre, réduisant ainsi la charge cognitive intrinsèque et augmentant les ressources cognitives pertinentes. La théorie de l'apprentissage génératif explique également cet effet (Fiorella & Mayer, 2018). L'effet bénéfique de l'imagination sur l'apprentissage est aussi soutenu par le principe de l'apprentissage génératif, qui valorise l'engagement actif des apprenants dans le traitement cognitif du contenu (Fiorella & Mayer, 2022). Cet engagement est crucial car il implique une attention soutenue aux informations pertinentes, leur organisation

mentale dans la MdT, et leur intégration avec les connaissances préalables stockées en MLT (Fiorella & Mayer, 2015a, 2016 ; Wittrock, 1974, 1989). Selon, la théorie de l'apprentissage génératif, le processus d'imagination commence lorsque les apprenants sélectionnent les éléments pertinents du contenu pour les inclure dans leurs représentations mentales (activant ainsi le processus de sélection cognitive). Ils organisent ensuite ces éléments de manière spatiale au sein de leurs représentations mentales (activant ainsi le processus d'organisation cognitif). Enfin, en transformant les informations verbales en représentations visuelles, les apprenants établissent des liens entre les connaissances préexistantes et les connaissances nouvelles acquise via le matériel d'apprentissage (activant ainsi le processus d'intégration cognitif) (tableau 1).

Effet de renversement de l'expertise

Les recherches soulignent que l'efficacité des stratégies d'apprentissage, (dont l'imagination) peut être influencées par plusieurs facteurs, notamment le niveau de connaissances préalables. Cette idée est particulièrement illustrée par l'effet de renversement de l'expertise, qui souligne l'impact prépondérant des connaissances antérieures sur l'efficacité des méthodes d'enseignement (Kalyuga, 2007; Kalyuga et al., 2003; Khacharem et al., 2013a). Ce phénomène, bien documenté dans la littérature sur la TCC, survient lorsque des techniques pédagogiques initialement bénéfiques pour des novices deviennent moins efficaces, voire contre-productives, à mesure que le niveau d'expertise des apprenants augmente, et inversement. (Kalyuga, 2006 ; Kalyuga et al., 2003 ; Kalyuga et al., 2001). L'effet de renversement de l'expertise suggère donc une inversion dans la performance relative des méthodes pédagogiques en fonction de l'évolution des connaissances des apprenants dans un domaine spécifique. Depuis sa première identification à la fin des années 1990, ce phénomène a été observé dans de nombreuses études couvrant un large éventail de matériaux pédagogiques soit sous la forme d'une inversion partielle (avec une interaction significative, mais des

différences non significatives pour les novices ou les experts), soit sous la forme d'une inversion totale (une interaction désordonnée avec des différences significatives à la fois pour les novices et les experts) (Kalyuga & Renkl, 2010).

De nombreuses études ont exploré la relation entre l'efficacité de l'imagination et les niveaux d'expertise des apprenants. Par exemple, Ginns et ses collaborateurs (2003) ont conduit deux expériences pour examiner les effets de l'apprentissage par l'imagination en manipulant les niveaux de connaissances des apprenants. Dans la première expérience, des étudiants ayant des connaissances limitées dans un langage de programmation informatique (HTML) ont été répartis en deux groupes : l'un étudiant des exemples concrets, et l'autre imaginant les étapes nécessaires. Les résultats ont révélé que les apprenants ayant étudié les exemples concrets ont obtenu de meilleurs résultats au post-test que ceux ayant fait appel à l'imagination. La seconde expérience a impliqué des élèves du secondaire possédant des connaissances préalables en géométrie. Il a été constaté que ces participants bénéficiaient davantage de l'imagination des étapes de la solution après avoir étudié des exemples concrets plutôt que de simplement répéter les exemples. Des résultats similaires ont également été rapportés dans d'autres études (Cooper et al., 2001 ; Sweller & Leahy, 2008), corroborant ainsi l'influence du niveau d'expertise sur l'efficacité de l'imagination dans le processus d'apprentissage.

Pour explorer l'interaction entre l'imagination et le niveau d'expertise dans l'apprentissage de stratégies tactiques en basketball, Mguidich et al. (2024)² ont mené une étude impliquant des joueurs de divers niveaux d'expertise (experts vs novices). Ces joueurs ont été répartis en deux groupes : un groupe d'étude, qui a écouté passivement des instructions verbales, et un groupe d'imagination, qui s'est activement engagé dans la visualisation mentale des mouvements tactiques. L'efficacité de l'apprentissage a été mesurée à travers trois types de

² **Mguidich, H., Zoudji, B., & Khacharem, A. (2024).** An expertise reversal effect of imagination in learning from basketball tactics. *Psychological Research*, 1-11. <https://doi.org/10.1007/s00426-024-01954-9>

tests. Le premier, un test de rappel verbal, consistait en huit questions à choix multiples sur les positions et actions spécifiques des joueurs (ex, « sur quel joueur le centre #5 fait-il un écran ? »). Le deuxième test, une tâche de dessin, demandait aux participants de représenter sur une feuille contenant quatre terrains de basket vides, l'évolution précise de la situation scène de jeu, en indiquant les positions et actions correctes des joueurs. Enfin, le test de reconnaissance consistait à présenter aux joueurs 32 images illustrant différentes actions de jeu (16 étaient issues du système tactique étudié et 16 étaient des distracteurs). L'analyse de la précision a été réalisée à l'aide des mesures de détection du signal, notamment la sensibilité (d') et le biais de réponse (c), suivant la méthodologie de Green et Swets (1966). La figure 5 montre un exemple d'action de jeu tirée du test de reconnaissance.

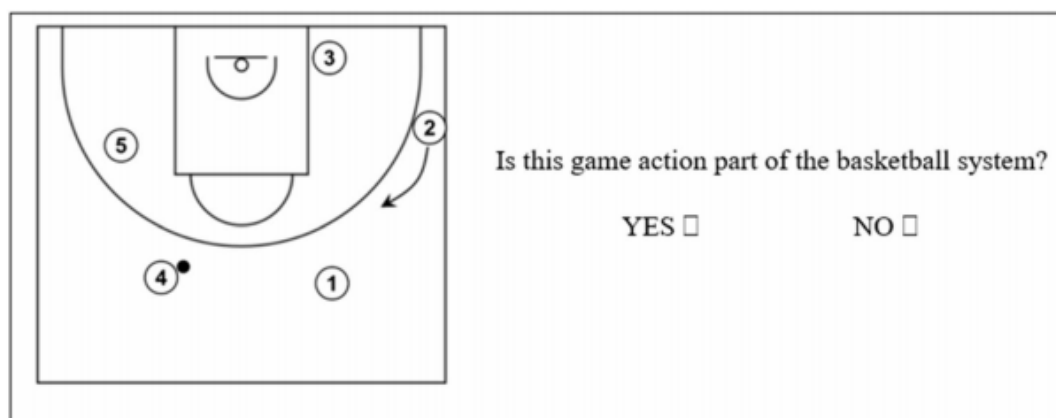


Figure 5. Extrait d'un exemple d'action de jeu issue du test de reconnaissance utilisé dans l'étude de Mguidich et al. (2024)

Les résultats de l'étude ont révélé que les joueurs novices bénéficiaient davantage de la condition d'étude traditionnelle (meilleures performances en termes de rappel verbal, de dessin et de reconnaissance). Cependant, cette tendance s'inversait chez les apprenants experts, qui tiraient un plus grand bénéfice de la condition d'imagination – indiquant ainsi un effet de renversement de l'expertise (Kalyuga, 2007; Khacharem et al., 2015). Cette divergence s'explique par le fait que les novices, possédant des connaissances de base limitées dans le domaine du basketball, ont besoin de maîtriser ces concepts tactiques fondamentaux avant de

pouvoir construire une représentation mentale de la scène. Sans une solide compréhension des principes tactiques fondamentaux, ils sont moins à même de bénéficier pleinement d'une approche basée sur l'imagination. À l'inverse, les joueurs experts, qui possèdent déjà une bonne compréhension des concepts tactiques de base, trouvent dans l'usage de l'imagination un outil puissant pour enrichir et approfondir leur compréhension. Pour eux, l'imagination facilite la création de schémas cognitifs complexes, permettant une intégration et une application plus sophistiquées des connaissances déjà acquises.

La Difficulté désirable : Un pilier de l'apprentissage profond

L'expression "No pain, no gain" (Pas de douleur, pas de gain), bien connue dans le monde sportif, trouve également un écho dans les contextes d'apprentissages classiques. Ce dicton illustre parfaitement le concept de "difficulté désirable", une notion clé dans les approches modernes de l'enseignement et de la formation. La "douleur" mentionnée ici n'est pas de nature physique, mais fait plutôt référence à un inconfort et un effort mental nécessaires pour surmonter des défis intellectuels. Ces défis, bien qu'ils puissent sembler peu efficaces à court terme, s'avèrent bénéfiques sur la durée (Ackerman & Zalmanov, 2012). En effet, sans effort, il y a stagnation, tandis que les défis, même s'ils sont inconfortables, favorisent un apprentissage durable. La difficulté désirable implique l'intégration intentionnelle de défis dans les programmes d'éducation/de formation, ajustés pour maximiser l'engagement et l'effort des apprenants. Ce dosage précis de la difficulté ne vise pas à décourager, mais à stimuler un apprentissage actif et approfondi. Les défis sont donc initialement perçus comme ardues en raison de l'effort exigé et des résultats non immédiats, mais ils sont essentiels pour l'acquisition d'une compréhension profonde et la rétention à long terme des connaissances.

Une stratégie efficace pour intégrer la "difficulté désirable" dans l'acquisition des compétences motrices consiste à utiliser l'interférence contextuelle. Cette méthode consiste à

introduire des perturbations (ou des interférences) dans la MdT en modifiant aléatoirement l'ordre des tâches lors de chaque essai. L'interférence contextuelle distingue nettement la performance de l'apprentissage. La performance, observable à court terme, est influencée par des facteurs temporaires et ne reflète pas nécessairement l'apprentissage durable. Pour évaluer l'apprentissage à long terme de manière fiable, des tests de rétention ou de transfert sont nécessaires, généralement après une période minimale de 24 heures (Schmidt & Lee, 2019). En pratique, bien que la méthode de pratique bloquée et ordonnée (ex, AA-BB-CC) puisse sembler supérieure en termes de performance initiale, les tests de rétention révèlent que la pratique avec un ordre aléatoire des tâches (ex, CB-AC-BA) favorise un apprentissage plus approfondi que la méthode bloquée.

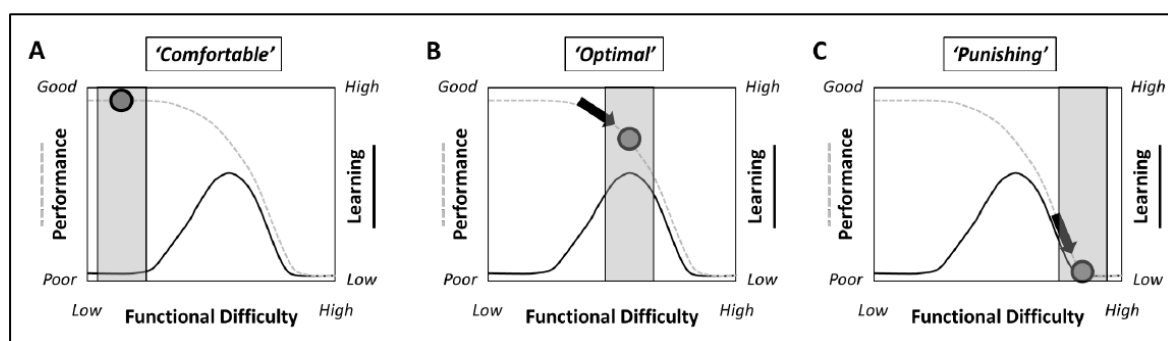


Figure 6. Une illustration conceptuelle de l'hypothèse du point de défi (Guadagnoli & Lee, 2004), présentant trois niveaux différents de difficulté fonctionnelle (A, B et C).

L'"hypothèse du point de défi" de Guadagnoli et Lee (2004) – qui s'appuie sur les principes de la difficulté désirable – examine également comment les défis (qualifiés également de "difficultés relatives" ou difficultés fonctionnelles) impactent la performance et l'apprentissage. Selon cette hypothèse, un faible niveau de défi est associé à une meilleure performance, alors que l'augmentation du défi tend à réduire la performance. Cependant, l'impact sur l'apprentissage suit une courbe en U inversé : un niveau de défi insuffisant restreint l'apprentissage, ce qui est représenté sous le terme "difficulté confortable" (figure 6A). À mesure que la difficulté augmente, l'apprentissage s'intensifie, ce qui est représenté sous le terme de "difficulté optimale" ou "désirable" (figure 6B). À l'opposé, un niveau de défi

excessivement élevé s'avère néfaste pour l'apprentissage, ce qui est représenté sous le terme "difficulté punitive" (figure 6C).

Il est crucial de reconnaître que la perception de la difficulté du matériel d'apprentissage peut varier selon les individus. Si l'apprenant ne dispose pas des connaissances ou des compétences préliminaires requises pour aborder les difficultés générées par le matériel ou la tâche d'apprentissage, ces défis peuvent se transformer en difficultés « indésirables ». Par conséquent, le niveau de difficulté optimal dépend du niveau de connaissance préalable de l'apprenant (Figure 7). Ce qui peut être considéré comme une difficulté confortable pour un expert peut être perçu comme punitive pour un novice, de même ce qui peut être considéré comme une difficulté confortable pour un novice peut être perçu comme confortable pour un expert. Ainsi, selon le concept de difficulté désirable, intégrer un degré de difficulté relativement élevé est nécessaire pour stimuler un traitement actif du contenu, tel que la génération ou l'inférence d'informations de la MLT. Cela pourrait donc donner lieu à des représentations de connaissances moins susceptibles d'être oubliées, et donc plus durables dans le temps (Bjork & Bjork, 2011).

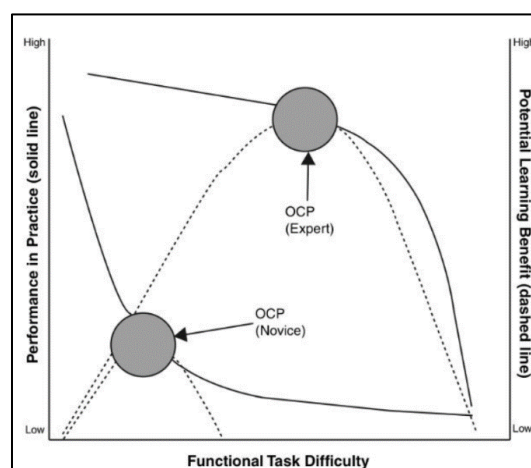


Figure 7. La relation entre l'apprentissage, la performance et le point de défi optimal pour deux apprenants (expert et novice)

Bien que des études spécifiques testant l'hypothèse de la difficulté désirable dans le contexte de l'apprentissage par l'imagination soient inexistantes, il est plausible de considérer que l'acte

d'imaginer constitue un processus mental exigeant, impliquant la création d'images mentales à partir de textes. Face à cette tâche, les apprenants peuvent rencontrer des difficultés qui révèlent des lacunes dans leur compréhension, les poussant ainsi à activer leurs capacités métacognitives (Schleinschok et al., 2017). Plus spécifiquement, ils sont incités à formuler des inférences mentales et à approfondir leur réflexion sur le contenu, ce qui tend à améliorer significativement l'assimilation des informations (Chi & Wylie, 2014). Bien que ce processus puisse ralentir initialement le rythme d'apprentissage par rapport à une écoute ou lecture passive, il est bénéfique à long terme. En effet, l'effort d'imaginer un contenu et de générer des inférences mentales enrichit la mémorisation, créant des souvenirs plus durables et un plus grand nombre d'indices facilitant le rappel des informations, en particulier lorsqu'elles sont évaluées après un certain temps (Bjork & Bjork, 2011 ; Bjork, 1994).

Néanmoins, ces assertions restent hypothétiques et non vérifiées par des études expérimentales. Cette thèse cherche à combler cette lacune en explorant les effets à long terme de l'apprentissage par l'imagination, spécifiquement dans le contexte de l'apprentissage des instructions tactiques en basketball.

Chapitre 2 : Does imagination enhance learning? A systematic review and meta-analysis

Ce chapitre a fait l'objet d'un article publié :

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Does imagination enhance learning? A systematic review and meta-analysis³

Abstract

Imagination-to-learn is a specific learning strategy that has been studied in many academic fields. The present study investigated whether imagination is beneficial overall for learning compared to conventional study strategies, while also identifying moderator factors affecting the global effect. A meta-analysis was conducted by scientifically rigorous experiments comparing the learning outcomes of students who were asked to form a mental image of the events described in learning material while reading (imagination condition) or were given no imagination instructions (control condition). A total of 21 experimental studies published on the PsycINFO, Web of Science, ProQuest Dissertations and Theses, ERIC and Google Scholar databases were included, yielding 70 pair-wise comparisons with N= 2625 participants. An overall positive effect of imagination-to-learn was found for both retention ($g^+ = 0.40$, 95% CI [0.23, 0.58], $z = 4.63$, $p < .001$) and transfer ($g^+ = 0.51$, 95% CI [0.22, 0.43], $z = 3.43$, $p < .001$) performance. However, analysis of the funnel plots showed that publication bias was present in the reporting of learning outcomes. Analysis of the moderators indicated that the effect sizes differed significantly only with respect to learners' prior knowledge for transfer performance and their educational level for retention scores. Based on these findings, the present study provides important directions for future research and practices.

Keywords: Imagination, Meta-analysis, Learning, Instructional designs, Prior Knowledge

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Introduction

In recent decades, the technique of imagination, which refers to the mental reproduction of a procedure or concept (Sweller et al., 2011a), has garnered significant attention and interest from educational researchers. This technique has been described using various terms by different researchers, such as “symbolic rehearsal” (Sackett, 1934, 1935), “imaginary practice” (Perry, 1939), “introspective rehearsal” (Egstrom, 1964), “imagery” (Page, 2000; Page et al., 2001), “mental imagery” (Liu et al., 2004), and “mental practice” (Page et al., 2009; Weiss et al., 1994). Several studies have consistently shown that learners perform significantly better when engaged in imagination (mental practice) conditions than under traditional study conditions. In the field of educational psychology, research on mental imagery can be categorized into two branches based on its learning objectives (Leopold & Mayer, 2015). The first branch of research aims at learning factual information, while the second branch focuses on exploring the role of imagination in learning procedures or concepts. Within the first branch of research, an imagination effect has been consistently observed when students are asked to imagine pictures while engaging with narrative facts. This effect has been established by numerous researchers over a span of more than 40 years (Pressley, 1976; Rasco et al., 1975; Kulhavy & Swenson, 1975). In a study conducted by Pressley (1976), elementary school students were instructed on how to form mental images and asked to read a 950-word story while actively creating pictures in their minds. In contrast, participants in the control group were asked to read the story and use any strategies they could to remember it. The findings showed that learners in the imagery group demonstrated better recall of factual details from the story compared to those in the control group. These findings have been replicated by Gambrell and Jawitz (1993) with fourth-grade students, Centre et al. (1999) with seven-year-old children, Kulhavy and Swenson (1975) with sixth-grade learners, and Rasco et al. (Experiment 1, 1975)

with postsecondary students. However, studies conducted by Anderson and Kulhavy (1972) with high school students, Rasco et al. (Experiment 2, 1975) with high school students, and Woloshyn et al. (1990) with postsecondary students did not find any significant difference in the performance between the imagery group and the control group. In a comprehensive literature review examining the impact of imagery strategies on story comprehension, De Koning and Van der Schoot (2013) found compelling evidence supporting the use of explicit mental imagery instructions. Their review concluded that instructing readers, particularly elementary school children and individuals identified as poor readers, to create mental pictures in their minds was most likely to enhance reading comprehension.

In the second research branch, focusing on memory for procedures or concepts, research has also identified an imagination effect (Cooper et al., 2001; Ginns, 2005; Ginns et al., 2003; Leahy & Sweller, 2004, 2005; Tindall-Ford & Sweller, 2006; Ignatova et al., 2020). This effect is observed when students, who are provided with instructions to imagine a procedure or concept, exhibit better performance on tests compared to learners who are solely instructed to study the same material. Through the process of imagination, learners construct mental representations in the form of mental images to depict the content of a lesson. This content can encompass scientific texts that provide descriptions or explanations of academic subjects (e.g., imagining the content of a scientific text detailing the workings of the human respiratory system) or handbooks that demonstrate the execution of specific tasks (e.g., imagining the application of geometry rules or the utilization of a bus schedule) (Fiorella & Mayer, 2015b). Previous research has consistently demonstrated the potential benefits of learning through imagination as an instructional technique, leading to improved learning outcomes. For instance, Leutner et al. (2009) conducted a study with high school students, revealing that those who engaged in imagining each paragraph of a scientific text about water molecules exhibited a better understanding compared to their peers who solely studied the text

content. Similarly, Leopold and Mayer (2015) conducted two experiments, both showing that students who participated in an imagination condition while learning about the human respiratory system displayed superior learning performance on both immediate and delayed tests compared to students in a control condition. However, in contrast, Lin et al. (2017) conducted a study with college students and found no significant difference in comprehension post-test performance between those who were instructed to create a mental image after reading a lesson on the human cardiovascular system and those who were only asked to read the lesson.

The positive effect of imagination on learning is largely explained from the perspective of cognitive load theory (CLT, Sweller et al., 2019; Sweller et al., 2011b). CLT categorizes cognitive load into two distinct types that are closely related to working memory: intrinsic and extraneous cognitive load. The combined impact of these two load sources contributes to the overall cognitive load experienced by the learner. Intrinsic cognitive load refers to the inherent complexity of information and its interaction with the learner's prior knowledge. It is influenced by the number of elements that must be processed simultaneously in working memory to achieve the instructional objective (Sweller, 2010). On the other hand, extraneous cognitive load arises from unnecessary cognitive processes caused by the presentation of information to learners or the tasks they have to perform. For effective learning, it is essential to design tasks in a manner that optimizes the use of available WM capacity, allowing learners to invest their mental effort efficiently. To achieve this, efforts should be made to minimize extraneous load, freeing up working memory capacity and potentially increasing resources allocated to intrinsic cognitive load (also referred to as germane processing) (Paas & Van Merriënboer, 2020). Imagination, according to CLT, enables learners to explicitly direct their limited WM resources to the interacting elements of intrinsic load, reducing extraneous load and promoting germane resources. Generative learning theory (Wittrock, 1974, 1989) provides an additional theoretical explanation on the use of imagination as a learning aid. According to this theory, when learners

actively engage in an appropriate cognitive processing during learning, such as attending to important incoming information, mentally organizing it to a coherent statement in WM, and integrating it with relevant prior knowledge from long-term memory, deep learning of the material is likely to occur (Fiorella & Mayer, 2015b, 2016, Wittrock, 1974, 1989). Generative learning activities, such as generating imagination, are designed to activate each of these three cognitive processes (Fiorella & Mayer, 2015b). First, learners must select the pertinent components in the text to include in their mental images (i.e., activate the cognitive process of selection in generative learning theory). Second, learners must spatially arrange the components in their mental images (i.e., activate the cognitive process of organizing in generative learning theory). Third, by translating the text from verbal to visual form of presentation, learners connect their existing knowledge with the material (i.e., activate the cognitive process of integrating in generative learning theory).

A number of recent studies have demonstrated significant interactions between levels of learner expertise and imagination effectiveness. According to the expertise reversal effect, instructional techniques and procedures that are effective for novice learners may become ineffective, or even harmful, for more experienced learners, and vice versa (Castro-Alonso et al., 2021; Kalyuga, 2011, 2007). Building on this notion, Ginns et al. (2003) conducted two experiments examining the effects of learning through imagination by manipulating learners' knowledge levels. In the first experiment, university students with low prior knowledge of a computer programming language (HTML) were assigned to either study worked examples or imagine the necessary steps. The results revealed that learners who studied the worked examples performed better on the post-test than those who engaged in imagination. The second experiment involved secondary school students who had some prior knowledge in geometry. It was found that these participants benefited more from imagining the solution steps after studying the worked examples compared to repeatedly studying the examples. Similar findings

have also been reported in other studies (Cooper et al., 2001; Sweller & Leahy, 2008) corroborating the influence of expertise level on the effectiveness of imagination in learning. In addition to prior knowledge, the level of element interactivity is another factor that may influence the imagination effect. Element interactivity refers to the extent to which a learning task requires the learner to simultaneously process multiple pieces of interrelated information in his or her working memory in order to understand and acquire a particular concept or procedure (Cerpa et al., 1996; Chandler & Sweller, 1996; Sweller, 2003). According to CLT, materials with low element interactivity contain relatively few elements that relate weakly to each other and therefore result in relatively low load on working memory. In contrast, materials with high element interactivity contain numerous interacting elements and therefore produce a higher load on working memory (Ben Chikha et al., 2023a; Sweller et al., 1998). In this context, Leahy and Sweller (2005) conducted a study that demonstrated the interaction between the level of element interactivity and the imagination effect. They found that the effect of imagination increased as the level of element interactivity increased. Specifically, when learners were asked to imagine materials with low element interactivity, no significant benefits were observed compared to learners who solely studied the same materials. However, for materials with high element interactivity, learners instructed to imagine the materials performed better than those who only studied them.

Given the inconsistent findings in prior studies concerning the impact of imagination on performance outcomes, several meta-analyses have been conducted to examine the efficacy of this instructional strategy and to identify potential factors that contribute to its effectiveness. The initial meta-analyses conducted by Feltz and Landers (1983) explored the effectiveness of interventions incorporating both mental practice and mental preparation, which encompass a wide range of strategies aimed at enhancing performance. Although this meta-analysis provided preliminary evidence supporting the effectiveness of mental practice on performance,

it was difficult to draw specific conclusions about the effectiveness of mental practice as an individual strategy. To overcome this limitation, a subsequent meta-analysis conducted by Driskell et al. (1994) exclusively included studies that employed mental practice interventions. This analysis demonstrated a moderate positive effect of mental practice on performance when compared to no-treatment control conditions, resulting in an effect size of $d = 0.53$, based on 62 effect sizes from 35 studies. More recently, in the field of academic learning, Fiorella and Mayer (2015a) conducted a comprehensive meta-analysis to examine the impact of imagination on student performance. The results of this study revealed that when students were given instructions to generate mental imagery during a lesson, there was a significant improvement in their performance on transfer and retention tests in sixteen out of twenty-two cases, in comparison to a control group that did not receive similar instructions ($d = 0.65$). Concerning boundary conditions, the impact of imagination is particularly pronounced for learners with a high level of experience, as well as when the instructional materials are well designed ($d = 0.77$ based on sixteen comparisons).

The Current Study

Fiorella and Mayer's meta-analysis (2015a) has played a crucial role in advancing our comprehension of the impact of imagery on learning, particularly in relation to retention and transfer. However, it is imperative to acknowledge the limitations of the study and explore ways to address them in order to enhance the overall findings. *Firstly*, a notable limitation of the study is its exclusion of research conducted in the first branch of mental imagery research, which specifically focuses on learning factual information. This omission hampers the breadth and generalizability of the findings, as it neglects an important aspect of mental imagery's influence on learning. To overcome this limitation, incorporating relevant studies from this branch of research is crucial. *Secondly*, the imagination effect has emerged as a distinct and prominent area of research in the field of psychology of education, leading to a

significant number of experimental investigations. Remarkably, these studies have revealed several potential moderators (e.g., content complexity, material modality, etc.) that were not taken into account in the previous research. Integrating these potential moderators into the present study will provide a more nuanced understanding of the effects of mental imagery on learning outcomes. *Thirdly*, Fiorella and Mayer's meta-analysis (2015a) did not adhere to PRISMA guidelines in terms of assessing risk of bias and heterogeneity. The present study will rigorously follow the PRISMA guidelines, ensuring transparency, replicability, and a more rigorous approach to the meta-analysis. By addressing these limitations and including recently published articles, the present study aims to provide a more comprehensive understanding of the effectiveness of imagery on learning outcomes.

The following hypotheses were formulated based on the existing scientific literature:

1. Our first hypothesis (Hypothesis 1) predicted that imagination would have a significant positive effect on overall learning performances, as measured by retention and transfer tests, in line with findings from Fiorella and Mayer (2015a).
2. Drawing on the expertise reversal effect, our second hypothesis (Hypothesis 2) posited that expertise level would be a significant moderator of the effect of imagery on learning performances. We anticipated that effect sizes would be significantly larger for expert learners compared to novices.
3. Building on research by Leahy and Sweller (2005, 2008), our third hypothesis (Hypothesis 3) proposed that the effect of imagery may increase as material complexity increases. Therefore, we hypothesized that material complexity would moderate the effectiveness of mental imagery on learning performance, with effect sizes being significantly larger for complex materials compared to simple material.

As there were no theoretical considerations available for the remaining moderator variables, we formulated hypotheses by drawing on relevant research findings from other

fields, extrapolating insights that could be applied to our study:

4. Considering the strong correlation between educational level and domain-specific prior knowledge, as indicated by Schneider et al. (2018) and Van der kleij et al. (2015), our fourth hypothesis (Hypothesis 4) suggested that older learners would benefit more from imagination than younger learners in terms of retention and transfer scores.
5. Guided by Mayer's (2001) cognitive theory of multimedia learning (CTML), which emphasizes the importance of reducing the time between information sources (temporal contiguity), our fifth hypothesis (Hypothesis 5) proposed that learners would derive greater benefits from simultaneous processing (studying while imagining) rather than sequential processing (studying, then imagining). This hypothesis assumes that separating the processing of information in time may divert mental resources to extraneous activities, hindering the effectiveness of the imagery process).
6. Taking into account the influence of medium on learning performance, as shown by Mangen et al. (2013), our sixth hypothesis (Hypothesis 6) hypothesized that learners who read and imagined texts in print would outperform learners who read and imagined texts digitally. This hypothesis draws on the findings that reading linear narrative and expository texts on paper leads to better reading comprehension compared to reading the same texts on a computer screen.
7. Our seventh hypothesis (Hypothesis 7) posited a greater impact of imagination on learning outcomes in mathematics compared to other learning domains. This hypothesis was derived from previous findings (e.g., Berney & Bétrancourt, 2015; Schneider, 2015), suggesting that instructional design benefits were more pronounced in mathematics due to its complex information and highly interactive elements, distinguishing it from domains such as biology and history.

Method

A systematic review and meta-analysis were conducted to analyze and integrate the effects of imagination on learning in an academic context. The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guideline was followed when conducting and reporting this study (Moher et al., 2015).

Search Strategy

To identify relevant studies on the effects of imagination on learning, we conducted a comprehensive search across multiple computerized databases including PsycINFO, Web of Science (WOS), Education Resources Information Centre (ERIC), Google Scholar, and ProQuest Dissertations and Theses databases. The search was not restricted by time, enabling us to explore relevant literature across all available time periods. For the literature search, we employed various combinations of the following keywords: (“Imagination” OR “Imagery” OR “Mental imagery” OR “Mental practice” OR “Mental rehearsal” OR “Covert rehearsal” OR “Gaze aversion”) AND (“Learning” OR “learning gain” OR “post-test” OR “learning outcome” OR “learning performance”). If relevant research was not available online, the authors were contacted personally.

Selection Criteria

To ensure the selection of relevant studies on the effect of imagination on learning, specific inclusion criteria were applied. These criteria included:

- a) Studies that provided a comparison treatment between an imagining group, where learners were instructed to imagine a concept or procedure, and a study group (i.e., control group), where learners were instructed to study the same concept or procedure.

- b) Studies that incorporated quantitative measurements related to learning (e.g., transfer and retention).
- c) Studies that involved male and/or female students of any age and skill level.
- d) The studies that provided sufficient statistical information to calculate an effect size.
- e) The studies that were published exclusively in English language.

Study Selection

Before deleting duplicates and downloading the articles for screening, the database search results were exported into Endnote reference management software. Two authors independently screened possible article titles and abstracts for eligibility based on the criteria. Any disagreements were handled through discussions until a consensus was reached. Following the search of electronic databases, a preliminary pool of 8320 entries was obtained. Additionally, a manual search of reference lists yielded 6 more entries, resulting in a total of 8326 papers for screening. Through the title screening process, 8227 entries were identified as irrelevant and filtered out, while 99 articles underwent a more detailed assessment based on their titles and abstracts. Subsequently, 78 articles were excluded from further consideration, comprising 7 studies without statistical results and 71 studies that did not investigate the effects of imagination on learning. However, the remaining 21 articles were found to be eligible. A thorough analysis of the complete texts confirmed their eligibility. The selection process for the articles is illustrated in Figure 1.

Coding of study features

For each available study, a coding was developed to extract the following variables. Table 1 lists all included studies with coded study features.

- 1) Authors and year of publication

- 2) Sample size (N)
- 3) Prior knowledge of the learners: Two levels of prior knowledge were differentiated: “high prior knowledge” and “low prior knowledge”. Studies were classified using information supplied by the authors for each research. Statistical data from these studies were utilized to code previous knowledge in cases where no explicit information was provided. The mean percentage of correct responses in relation to the maximum score achievable in the prior knowledge test was employed. If participants scored on average below 50% on the prior knowledge test, they were classified as having “low prior knowledge”. If participants scored above 50%, they were classified as having “high prior knowledge” (Schneider et al., 2018).
- 4) Level of element interactivity, which was categorized as low and high element interactivity, based on the coding system described by Sweller and Chandler (1994). The coding system provides detailed procedures for estimating the interactivity of individual elements.
- 5) Educational level of the participants, which was categorized as elementary school (USA Grades k–5), middle school (USA grades 6–8), or postsecondary (usually participants enrolled in university, aged 18 and above, adults).
- 6) Imagination time, which refers to whether learners were asked to imagine during reading the content or imagine after reading the content.
- 7) Medium, which was coded based on whether the lessons were presented on paper or via computer.
- 8) Learning domain was coded with the following five categories: (a) computer science, (b) reading, (c) language, (d) mathematics, or (e) science. The term

science was used to include biology-related subjects such as the respiratory system, cardiovascular system, and human blood.

- 9) Performance measures were categorized into “transfer” and “retention”. Retention can be defined as “remembering” - recognizing or reproducing learning content. In contrast, the transfer knowledge is defined as “understanding” (Mayer, 2014).

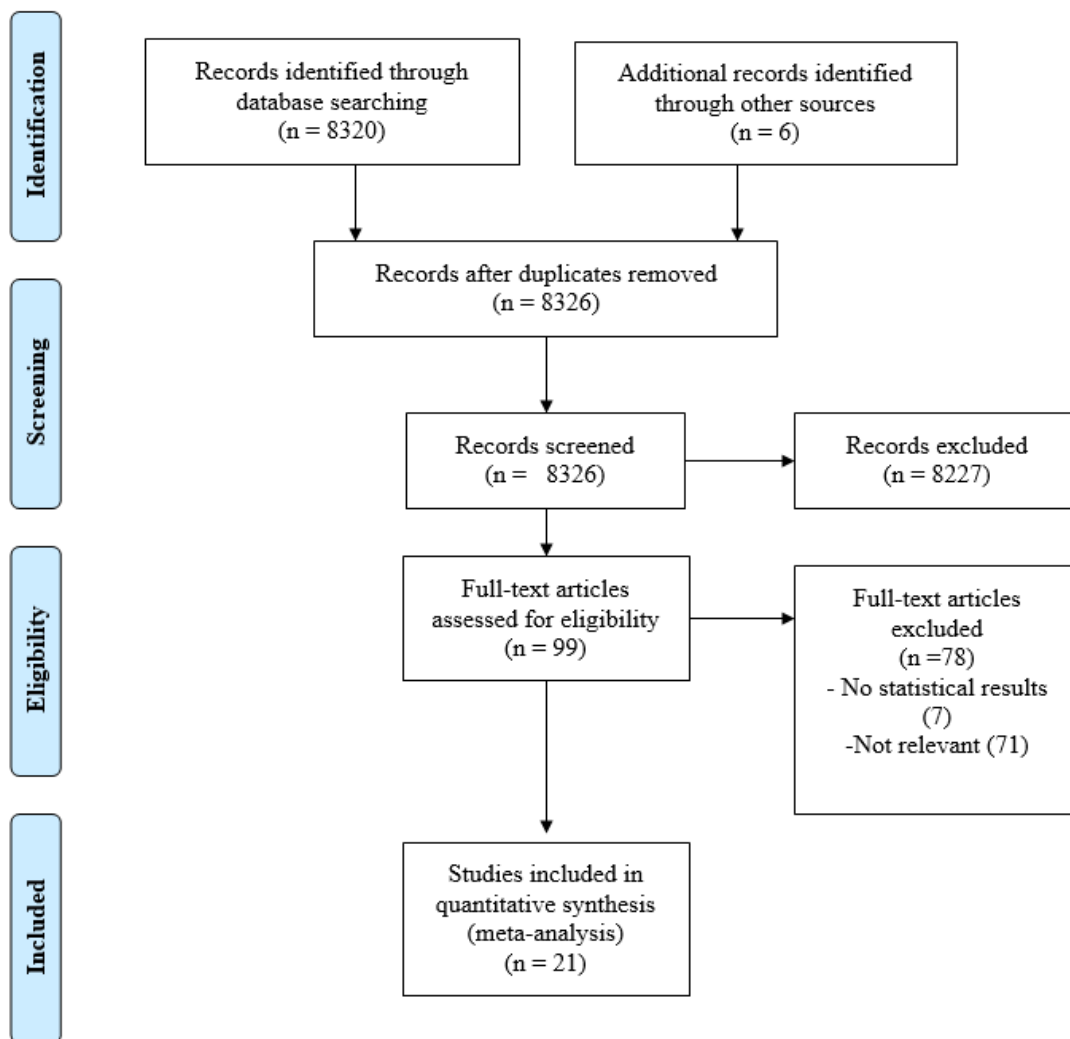


Figure 1. PRISMA flow diagram illustrating the different phases of the search and study selection

Assessment of Study Quality

The Quality Assessment Checklist for Survey Studies in Psychology (Q-SSP;

Protogerou & Hagger, 2020) was used to assess the quality of all studies. The Q- SSP was developed to assess the quality of survey studies in psychology (detailed item descriptions and assessment information can be found at <https://osf.io/5aepd>). The checklist consists of 20 items that assess quality criteria in four areas: introduction (rationale/variables), participants (sample/recruitment), data (collection/analysis/measurements/results/discussion), and ethics. Each item is scored as 'yes' if the criterion is met, 'no' if it is not met or if there are insufficient data, or 'not applicable' if the criterion does not apply to the study. The overall quality score is calculated as a percentage based on the proportion of 'yes' responses to the total number of applicable items for each study. Data extraction was independently performed by two reviewers who conducted coding exercises and established procedures to resolve ambiguities, resulting in high intercoder reliability between the two reviewers ($\kappa = 0.91$). Disagreements were resolved through discussion and consensus was always reached. Depending on the number of applicable items, studies must achieve a score of approximately 70% to be considered “acceptable”, while a score below this threshold indicates that the study may be of “questionable” quality. Table 2 displays the overall quality scores for each study obtained from the Q-SSP checklist.

Table 1. Summary of Studies Included in the Current Systematic Review and Meta-analysis

Study	Year	N	Domain	Medium	Imagination time	Element interactivity	Knowledge	Educational level	Learning outcome
Center et al.	1999	66	Reading comprehension	Paper	After	High	Low prior knowledge	Elementary school	Retention
Cooper et al., Exp 1	2001	28	Computer science	Computer	After	High	High prior knowledge	Middle school	Transfer
Cooper et al., Exp 2	2001	20	Computer science	Computer	After	High	High prior knowledge	Middle school	Transfer
Cooper et al., Exp 3	2001	22	Computer science	Computer	After	High	Low prior knowledge	Middle school	Transfer
Cooper et al., Exp 4 (HK)	2001	36	Computer science	Computer	After	High	High prior knowledge	Middle school	Transfer
Cooper et al., Exp 4 (LK)	2001	36	Computer science	Computer	After	High	Low prior knowledge	Middle school	Transfer
Cheng and Beal	2020	55	Science	Computer	During	High	Low prior knowledge	Postsecondary	Transfer Retention
Gambrell (1st graders)	1981	29	Reading comprehension	Paper	After	Low	High prior knowledge	Elementary school	Retention
Gambrell (3rd grader)	1981	29	Reading comprehension	Paper	After	Low	High prior knowledge	Elementary school	Retention
Gambrell	1982	28	Reading comprehension	Paper	After	Low	High prior knowledge	Elementary school	Retention
Gambrell and Jawitz	1993	60	Reading comprehension	Paper	During	Low	Low prior knowledge	Elementary school	Retention
Binns et al., Exp 1	2003	20	Computer science	Computer	After	High	Low prior knowledge	Postsecondary	Transfer
Binns et al., Exp 2	2003	26	Mathematics	Paper	After	Low	High prior knowledge	Middle school	Transfer
Ignatova et al., Exp 1 (T)	2020	22	Language	Paper	After	Low	Low prior knowledge	Postsecondary	Transfer
Ignatova et al., Exp 1 (D)	2020	22	Language	Paper	After	Low	Low prior knowledge	Postsecondary	Transfer

Ignatova et al., Exp 2 (T)	2020	15	Language	Paper	After	High	Low prior knowledge	Postsecondary	Transfer
Ignatova et al., Exp 2 (D)	2020	15	Language	Paper	After	High	Low prior knowledge	Postsecondary	Transfer
Kulhavy and Swenson	1975	34	Reading comprehension	Paper	After	Low	Low prior knowledge	Middle school	Retention
Leahy and Sweller, Exp 1 (FI)	2004	24	Science	Paper	After	High	High prior knowledge	Postsecondary	Transfer
Leahy and Sweller, Exp 2a (FI)	2004	16	Mathematics	Paper	After	Low	High prior knowledge	Elementary school	Transfer

Table 1. (continued)

Study	Year	N	Domain	Medium	Imagination time	Element interactivity	Knowledge	Educational level	Learning outcome
Leahy and Sweller, Exp 2b (FS)	2004	16	Mathematics	Paper	After	Low	High prior knowledge	Elementary school	Transfer
Leahy and Sweller, Exp 1a (LI)	2005	30	Mathematics	Paper	After	Low	Low prior knowledge	Elementary school	Transfer
Leahy and Sweller, Exp 1a (HI)	2005	30	Mathematics	Paper	After	High	Low prior knowledge	Elementary school	Transfer
Leahy and Sweller, Exp 1b (LI)	2005	30	Mathematics	Paper	After	Low	High prior knowledge	Elementary school	Transfer
Leahy and Sweller, Exp 1b (HI)	2005	30	Mathematics	Paper	After	High	High prior knowledge	Elementary School	Transfer
Leahy and Sweller, Exp 2a (LI)	2005	30	Mathematics	Paper	After	Low	Low prior knowledge	Elementary school	Transfer
Leahy and Sweller, Exp 2a (HI)	2005	30	Mathematics	Paper	After	High	Low prior knowledge	Elementary school	Transfer
Leahy and Sweller, Exp 2b (LI)	2005	30	Mathematics	Paper	After	Low	High prior knowledge	Elementary school	Transfer
Leahy and Sweller, Exp 2b (HI)	2005	30	Mathematics	Paper	After	High	High prior knowledge	Elementary school	Transfer
Leopold and Mayer, Exp 1	2015	43	Science	Computer	During	High	Low prior knowledge	Postsecondary	Transfer Retention
Leopold and Mayer, Exp 2	2015	48	Science	Computer	During	High	Low prior knowledge	Postsecondary	Transfer Retention
Leutner et al.	2009	56	Science	Paper	During	High	High prior knowledge	Postsecondary	Retention
Lin et al.	2017	40	Science	Computer	After	High	High prior knowledge	Postsecondary	Retention
Maher and Sullvian, Exp 1, (HR, O)	1982	28	Story	Paper	After	Low	High prior knowledge	Middle school	Retention
Maher and Sullvian, Exp 1, (LR, O)	1982	25	Story	Paper	After	Low	Low prior knowledge	Middle school	Retention
Maher and Sullvian, Exp 1, (HR, W)	1982	27	Story	Paper	After	Low	High prior knowledge	Middle school	Retention

Table 1. (continued)

Study	Year	N	Domain	Medium	Imagination time	Element interactivity	Knowledge	Educational level	Learning outcome
Maier and Sullivan, Exp 1, (LR, W)	1982	25	Story	Paper	After	Low	Low prior knowledge	Middle school	Retention
Maier and Sullivan, Exp 2, (HR, O)	1982	21	Story	Paper	After	Low	High prior knowledge	Elementary school	Retention
Maier and Sullivan, Exp 2, (LR, O)	1982	16	Story	Paper	After	Low	Low prior knowledge	Elementary school	Retention
Maier and Sullivan, Exp 2, (HR, W)	1982	22	Story	Paper	After	Low	High prior knowledge	Elementary school	Retention
Maier and Sullivan, Exp 2, (LR, W)	1982	16	Story	Paper	After	Low	Low prior knowledge	Elementary School	Retention
Pressley (HR)	1976	54	Story	Paper	After	High	High prior knowledge	Elementary school	Retention
Pressley (LR)	1976	32	Story	Paper	After	High	Low prior knowledge	Elementary school	Retention
Tindall-Ford and Sweller, Exp 1 (AV)	2006	22	Mathematics	Computer	After	High	High prior knowledge	Middle school	Transfer
Tindall-Ford and Sweller, Exp 1(V)	2006	22	Mathematics	Computer	After	High	High prior knowledge	Middle school	Transfer
Tiwari and Deore (2009)	2009	15	Computer Science	Computer	After	High	High prior knowledge	Postsecondary	Transfer
Woloshyn et al.	1990	40	Story	Paper	After	Low	High prior knowledge	Postsecondary	Retention

Table 2.Q-SSP Quality Assessment Score for Included Studies

QSSP	Centre et al. (1999)	Cheng and Beal (2020)	Cooper et al. (2001)	Gambrell (1981)	Gambrell (1982)	Gambrell and Jawitz (1993)	Ginns et al. (2003)	Ignatova et al. (2020)	Kulhavy and Swenson (1975)	Leahy and Sweller (2004)
1.Was the problem or phenomenon under investigation defined, described, and justified?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2.Was the population under investigation defined, described, and justified?	Yes	Yes	Yes	Not Stated Clearly	Yes	Yes	Yes	Yes	Yes	Yes
3.Were specific research questions or hypotheses stated?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4.Were operational definitions of all study variables provided?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5.Were participant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Not Stated	Yes

inclusion criteria stated?	Clearly									
6. Was the participant recruitment strategy described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7. Was a justification/rationale for the sample size provided?	No	No	No	No	No	No	No	No	No	No
8. Was the attrition rate provided?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9. Was a method of treating attrition provided?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10. Were the data analysis techniques justified?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11. Were the measures provided in the report (or in a supplement) in full?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12. Was evidence provided for the	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

validity of all the measures (or instrument) used?										
13. Was information provided about the person(s) who collected the data (e.g., training, expertise, other demographic characteristics)?	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes
14. Was information provided about the context (e.g., place) of data collection?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
15. Was information provided about the duration (or start and end date) of data collection?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
16. Was the study sample described in terms of key	No	No	Yes	Yes	Yes	No	No	No	No	No

demographic characteristics?										
17. Was discussion of findings confined to the population from which the sample was drawn?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
18. Were participants asked to provide (informed) consent or assent?	No	Yes	No	No	No	No	Yes	No	No	No
19. Were participants debriefed at the end of data collection?	No	No	No	No	No	No	No	No	No	No
20. Were funding sources or conflicts of interest disclosed?	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Score	66.66%	83.33%	77.78%	72.22%	72.22%	72.22%	83.33 %	77.78%	61.11 %	72.22 %

Table 2. (Continuation)

QSSP	Leahy and Sweller (2005)	Leahy and Sweller (2008)	Leopold and Mayer (2015)	Leopold et al. (2019)	Leutner et al. (2009)	Lin et al. (2017)	Maher and Sullivan (1982)	Pressley (1976)	Tindall- Ford and Sweller (2006)	Tiwari and Deore (2009)	Woloshyn et al. (1990)
1. Was the problem or phenomenon under investigation defined, described, and justified?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Was the population under investigation defined, described, and justified?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3. Were specific research questions or hypotheses stated?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4. Were operational definitions of all study variables provided?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
5. Were participant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

inclusion criteria stated?												
6.Was the participant recruitment strategy described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7.Was a justification/rationale for the sample size provided?	No	No	No	No	No	No	No	No	No	No	No	No
8.Was the attrition rate provided?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9.Was a method of treating attrition provided?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10.Were the data analysis techniques justified?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11.Were the measures provided in the report (or in a supplement) in full?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12.Was evidence provided for the	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

validity of all the measures (or instrument) used?											
13. Was information provided about the person(s) who collected the data (e.g., training, expertise, other demographic characteristics)?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Not Stated clearly
14. Was information provided about the context (e.g., place) of data collection?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
15. Was information provided about the duration (or start and end date) of data collection?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
16. Was the study sample described in terms of key	No	No	No	No	No	No	Yes	Yes	No	No	Yes

demographic characteristics?											
17. Was discussion of findings confined to the population from which the sample was drawn?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
18. Were participants asked to provide (informed) consent or assent?	No	No	Yes	Yes	No	Yes	No	No	No	No	No
19. Were participants debriefed at the end of data collection?	No	No	No	No	No	No	No	No	No	No	No
20. Were funding sources or conflicts of interest disclosed?	Yes	Yes	No	No	Yes	No	No	No	No	No	No
Score	77.77%	72.22%	77.78%	77.78%	77.78%	77.78%	77.78%	72.22%	72.22 %	66.67%	72.22%

Data Analysis

The data analysis was conducted using Comprehensive Meta-Analysis (CMA) version 3.0 (Borenstein et al., 2013) and IBM SPSS version 24 for Windows. Cohen's d was used as the effect size to be meta-analysed and was calculated as the difference between the means of the imagination group and the control group, divided by the pooled standard deviation of the two groups. A positive d value was indicative of the imagination effect. The effect size criterion for small, medium, or large effects was based on Hattie's (2009) study, which investigated more than 800 meta-analyses. For educational achievements, values of $d = 0.20$, 0.40 , and 0.60 were used to describe small, medium, and large effects, respectively. The mean and standard deviation reported in the studies were used to compute effect sizes for all pairwise comparisons. In cases where studies reported multiple effect sizes as single sample (e.g., when different measures were used to assess the same concept), these values were averaged within the respective studies. This approach, as employed by Lipsey and Wilson (2001), served to avoid any statistical interconnections between the effect sizes. Hedges' g^+ (standardized mean difference effect size) the weight mean effect sizes were also calculated based on the standardized difference, which defines a variation on Cohen's d (Lipsey & Wilson, 2001). The choice of Hedges's g was made to uniform (standardize) the variety of different psychometric scales used to evaluate outcomes in the studies.

The homogeneity of variance of the effect sizes was examined using the Q statistic obtained by the Comprehensive Meta Analysis software. The I^2 statistic was utilized to analyze the homogeneity test results, in addition to the Q statistics. The I^2 statistic is a more thorough metric that shows the percentage of variability related to true heterogeneity (Higgins & Thompson 2002). As a result, the Comprehensive Meta-Analysis Software's Q and I^2 statistics were employed to offer reliable information on the level of variance homogeneity across trials. The presence of heterogeneity was determined using a significant Q statistic (e.g., $p < .05$) and

is suggestive of moderators that may impact the study effect sizes. The I^2 statistic was employed in addition to the Q statistic to identify heterogeneity using the following recommended criteria (Higgins and Thompson 2002): percentages around 25%, 50%, and 75% signified moderate, medium, and high heterogeneity, respectively. As publication bias tests usually have low statistical power (Macaskill et al., 2001), it is suggested to assess publication bias using a variety of methods, instead of relying on the conclusion from a single test (Lin et al., 2018). To examine potential publication bias, we utilized funnel plots' potential asymmetries, Begg and Mazumdar's rank correlation test (Kendall's S statistic P–Q; Begg & Mazumder, 1994), Egger's linear regression test (Egger et al., 1997), and Duval and Tweedie's trim-and-fill test (Duval & Tweedie, 2000).

Results

Sample

Twenty-one articles with $k = 70$ pair-wise comparisons were included in the meta-analysis (see Table 1). The pair-wise comparisons included transfer of knowledge (34) and retention of learning (36) between with and without imagination conditions. The 21 studies were all published between 1975 and 2020, comprising 18 journal articles and three conference papers. The total number of participants in these studies was 2625. Among them, the majority were postsecondary (48.57%) followed by elementary school (32.86%), and middle school (18.57%). The topics covered in the studies were mostly from science domains (38.57%), reading (24.29%), mathematics (21.43%), computer science (10%), and language (5.71%).

Assessment of Study Quality

Based on Protogerou and Hagger's Q- SSP (2020), the majority of studies ($n = 18$) were of acceptable quality (score > 70%), and the remainder were of questionable quality (score between 60 and 70%). The most common problems were lack of justification for sample size and funding sources.

Retention

For retention scores, the overall Hedge's g effect size was statistically significant at 0.40 ($SE = 0.09$, 95% CI 0.23 to 0.58, $z = 4.63$, $p < .001$). This suggests that the comparisons between subjects revealed a notable imagination-to-learn effect. In other words, students demonstrated better retention scores when engaging in imagination (mental practice) compared to traditional study conditions. According to Hattie's (2009) guidelines for effect sizes in education, this effect can be considered as medium. Further examination of the Q statistic indicated that the effect sizes were heterogeneous ($Q_{value}=9.37$, $df=35$, $p < .001$; $I^2=61.93$). The I^2 statistic denotes that 62% of the variance is not attributed to sampling error or chance, suggesting the presence of one or more moderators contributing to this observed heterogeneity.

Impact of Moderator Variables for Retention Performance

Statistical data for moderator retention performance is outlined in Table 3. We examined learners' prior knowledge as a moderator by comparing learners with higher prior knowledge to those with lower prior knowledge. The findings showed a medium to large effect size for high prior knowledge learners ($g^+ = 0.55$) and a small to medium effect size for low prior knowledge ($g^+ = 0.35$). However, there were no significant differences between the two knowledge levels [$Q_B(1) = 1.66$, $p = .198$].

Furthermore, we investigated the influence of learning by imagination based on the element interactivity level of the learning materials. Element interactivity was categorized as high, and low. The results showed a significant and positive effect size for both high ($g^+ = 0.43$) and low ($g^+ = 0.35$) element interactivity levels, with effect sizes falling within the small to medium range for both categories. However, there were no significant differences between the two levels [$Q_B(1) = 0.34$, $p = .558$].

Additionally, we examined whether the effect of imagination-to-learn was moderated

by participants' educational level. The educational levels were categorized as elementary school, middle school, and postsecondary students. The analysis yielded significant differences among these levels [$Q_B(2) = 10.13, p < .001$]. The result showed that middle school students do not gain notable benefit from imagination techniques ($g^+ = -0.10$), while imagination proved beneficial for elementary students ($g^+ = 0.43$) with a medium effect sizes and postsecondary students with a medium to large effect sizes ($g^+ = 0.55$).

In terms of imagination time (refer to Table 3), compared comparison was made between “after reading” and “during reading” imagination. The results indicated a positive and statistically significant effect of imagining both after ($g^+ = 0.41$) and during ($g^+ = 0.40$) reading, with medium effect sizes for both instances. Furthermore, there was no significant difference between the two times [$Q_B(1) = 0.03, p = .954$]. This suggests that the efficacy of learning through imagination remains consistent, whether it occurs during or after reading.

Regarding the medium of the presentations, we compared studies presented via “computer” versus “paper”. We found medium significant effect sizes for both computer ($g^+ = 0.38$) and paper ($g^+ = 0.45$) presentations, as shown in Table 3, and our analysis showed no significant difference between the two modes [$Q_B(1) = 0.17, p = .684$]. This underscores the positive effect of imagination-to-learn regardless of the presentation medium.

Finally, we established the benefits of imagination-to-learn depending in the domain of the educational intervention. Upon analyzing studies conducted in reading and science, we found that studies conducted in the domains of science ($g^+ = 0.40$) and reading ($g^+ = 0.42$) exhibited medium positive effects. However, there were no significant differences between the two domains [$Q_B(1) = 0.02, p = .901$].

Table 3. Results of the Moderator analyses for retention: mean Hedge's g +, 95% Confidence Interval, Q_B and k

Moderators	Effect size		Test of Heterogeneity					
	g^+	k	SE	95% CI	Z-value	Q_B	df	p
Knowledge								
High prior	0.548	11	0.106	[0.340; 0.756]	5.157			
Low prior	0.348	25	0.113	[0.127; 0.570]	3.086			
Total between						1.658	1	0.198
Element interactivity								
High	0.433	23	0.113	[0.211; 0.656]	3.824			
Low	0.335	13	0.125	[0.089; 0.580]	2.674			
Total between						0.342	1	0.558
Educational level								
Elementary school	0.426	11	0.170	[0.170; 0.682]	3.264			
Middle school	-0.097	5	0.174	[-0.438; 0.244]	-0.555			
Postsecondary	0.548	20	0.106	[0.341; 0.756]	5.173			
Total between						10.127	2	0.006
Imagination time								
After	0.411	17	0.101	[0.212; 0.610]	4.051			
During	0.401	19	0.132	[0.142; 0.660]	3.039			
Total between						0.003	1	0.954
Medium								
Computer	0.377	18	0.103	[0.103; 0.650]	2.699			
Paper	0.445	18	0.259	[0.259; 0.632]	4.679			
Total between						0.166	1	0.684
Domain								
Reading	0.417	17	0.100	[0.222; 0.613]	4.191			
Science	0.397	19	0.133	[0.135; 0.658]	2.974			
Total between						0.015	1	0.901

Publication Bias for Retention Performance

Upon visually inspecting the funnel plot (Figure 2), no evidence of publication bias was detected. This conclusion was further supported by Begg and Mazumdar's rank correlation test (Kendall's S statistic $P-Q = 20.00$; tau without continuity correction = 0.03, $z = 0.27$, $p = 0.39$; tau with continuity correction = 0.03, $z = 0.25$, $p = 0.39$) and Egger's linear regression test (intercept = 1.03, $SE = 1.55$ 95% CI -2.13 to 4.19, $t = 0.66$, $df = 34$, $p = 0.26$). However, the

trim-and-fill test by Duval and Tweedie identified five missing studies, resulting in an adjusted ES of 0.30 (95% CI 0.13 to 0.47, $Q = 119.32$). These conflicting results can be attributed to the use of varying methods with distinct methodologies and underlying assumptions, leading to divergent outcomes. Each test has its own unique strengths and limitations, which ultimately influence the overall findings.

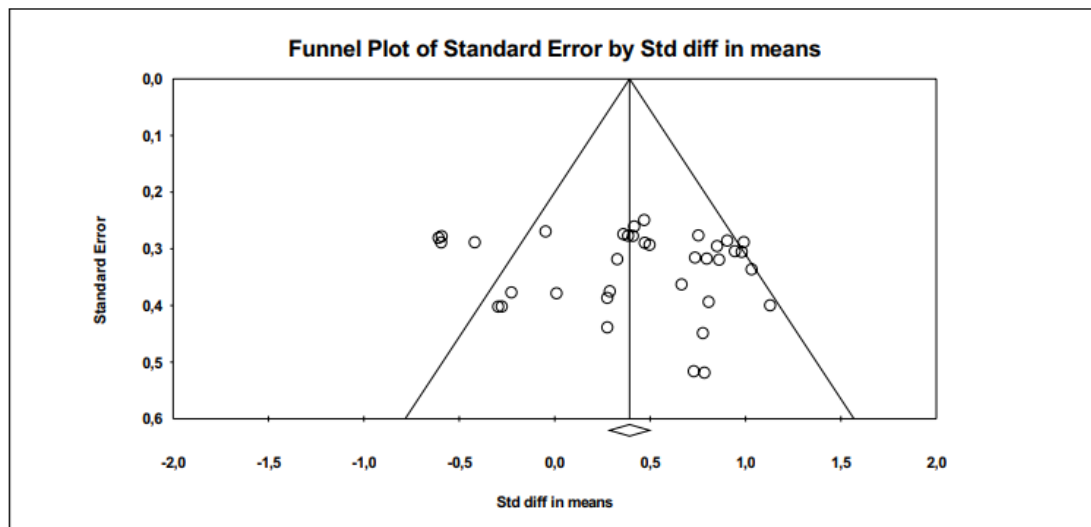


Figure 2. Funnel plot of the samples for retention included in the meta-analysis

Transfer

Regarding the performance in transfer tasks, the Hedge's g effect size showed a significant value of 0.51 ($SE = 0.15$, 95% CI 0.22 to 0.80, $z = 3.43$, $p < .001$). This suggests that when comparing different individuals, a notable "imagination-to-learn" impact was observed. Students achieved higher scores in transfer tasks when they engaged in imagination compared to traditional study methods. According to Hattie's (2009) standards for effect sizes in the field of education, this effect can be classified as ranging from medium to large. Further analysis of the Q statistic indicated heterogeneity in effect sizes ($Q_{value}=169.98$, $df=33$, $p < .001$; $I^2=80.59$). The I^2 statistic denotes that 81% of the variance is not attributed to sampling error or chance suggesting the presence of one or more moderators contributing to the heterogeneity.

Impact of Moderator Variables for Transfer Performance

Table 4. Results of the Moderator analyses for transfer: mean Hedge's g^+ , 95% Confidence Interval, Q_B and k

Moderators	Effect size		Test of Heterogeneity					
	g ⁺	k	SE	95% CI	Z-value	Q _B	df	p
Knowledge								
High prior	0.892	16	0.177	[0.546; 1.239]	5.047	6.945	1	0.008
Low prior	0.168	18	0.210	[0.802; 0.580]	0.801			
Total between								
Element interactivity								
High	0.474	24	0.167	[0.147; 0.802]	2.480	0.191	1	0.662
Low	0.638	10	0.334	[-0.017; 1.293]	1.909			
Total between								
Educational level								
Elementary school	0.155	12	0.225	[-0.285; 0.596]	0.692	3.963	2	0.138
Middle school	0.829	8	0.495	[-0.142; 1.800]	1.673			
Postsecondary	0.686	14	0.171	[0.351; 1.021]	1.021			
Total between								
Imagination time								
After	0.473	27	0.190	[0.099; 0.846]	2.481	0.471	1	0.493
During	0.660	7	0.196	[0.276; 1.044]	3.369			
Total between								
Medium								
Computer	0.455	16	0.193	[0.077; 0.832]	2.359	0.167	1	0.683
Paper	0.579	18	0.235	[0.119; 1.038]	2.467			
Total between								
Domain								
Computer	0.109	7	0.403	[-0.681; 0.898]	0.269	3.358	3	0.340
Language	1.040	4	0.369	[0.317; 1.763]	2.818			
Mathematics	0.467	15	0.264	[-0.051; 0.984]	1.766			
Science	0.681	8	0.179	[0.331; 1.031]	3.811			
Total between								

Statistical data for moderator transfer performance are outlined in Table 4. Transfer performance was significantly moderated by learners' prior knowledge. The effects were notably different between those with high and low prior knowledge [$Q_B(1) = 6.95, p < .001$]. Studies involving learners with low prior knowledge showed no significant effect ($g^+ = 0.17$), whereas those with high prior knowledge learners demonstrated a significantly larger effect size ($g^+ = 0.89$). This indicates that learners with high prior knowledge benefited more from

the imagination condition compared to those with lower prior knowledge.

The other moderators did not systematically influence transfer performance. There were no significant differences in terms of the element interactivity level of the learning materials [$Q_B(1) = 0.19, p = .662$]. The results showed a significant and positive effect size for both high ($g^+ = 0.47$) and low ($g^+ = 0.63$) element interactivity of the learning, with medium to large effect size for both categories. Additionally, there were no significant differences among participants' educational levels [$Q_B(2) = 3.96, p = .0138$]. The results revealed large positive effect sizes for both postsecondary students ($g^+ = 0.68$), and middle school students ($g^+ = 0.83$), and a small positive effect sizes for elementary school ($g^+ = 0.16$). In terms of imagination time, the results indicated a positive and statistically significant effect of imagining both after ($g^+ = 0.47$) and during ($g^+ = 0.66$) reading, with large effect sizes for both instances. Furthermore, there was no significant difference between the two imagination times [$Q_B(1) = 0.47, p = .493$]. This suggests that learning through imagination is effective regardless of whether it occurs during or after reading. For the medium of presentations, even though the studies that presented their content via computer ($g^+ = 0.46$) or paper ($g^+ = 0.58$) were associated with large significant effect size for both mediums, as shown in Table 4, our analysis showed no significant difference between the two presentations [$Q_B(1) = 0.17, p = .683$]. Finally, there were no differences in terms of educational intervention [$Q_B(3) = 3.36, p = .340$]. Analyzing studies conducted in computer science, language, mathematics, and science, it was found that studies conducted in the domains of science ($g^+ = 0.68$), mathematics ($g^+ = 0.46$), and language ($g^+ = 1.04$) exhibited large positive effects, while studies conducted in the domain of computer science ($g^+ = 0.11$) showed a small positive effect.

Publication Bias

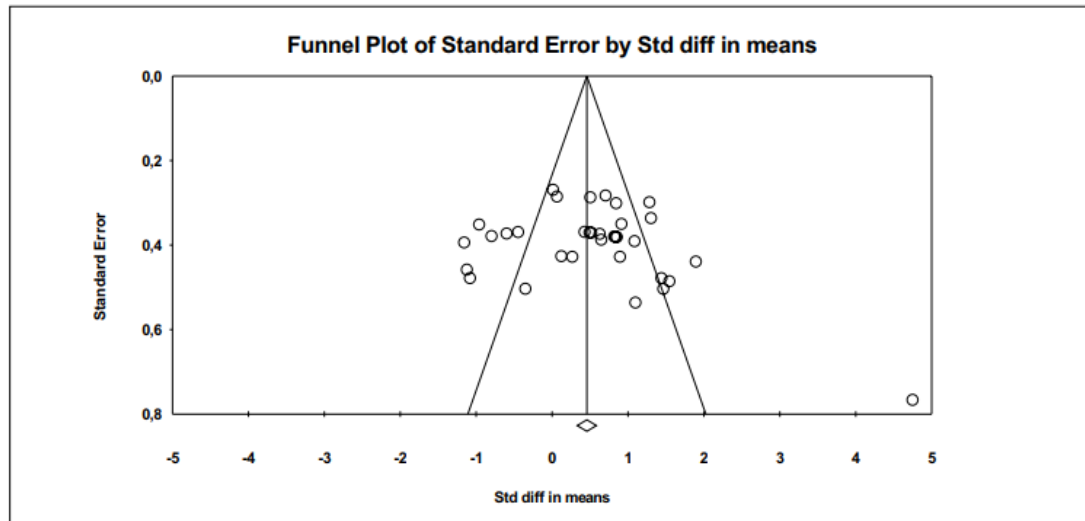


Figure 3. Funnel plot of the samples for transfer included in the meta-analysis

Upon visually inspecting the funnel plot (Figure 3), no evidence of publication bias was observed. This conclusion was further supported by Begg and Mazumdar's rank correlation test (Kendall's S statistic $P-Q = 79.00$; tau without continuity correction = 0.14, $z = 0.17$, $p = 0.12$; tau with continuity correction = 0.13, $z = 0.16$, $p = 0.12$) and Egger's linear regression test (intercept = 2.25, $SE = 1.97$ 95% CI -1.76 to 6.25, $t = 1.14$, $df = 13$, $p = 0.26$). However, the trim-and-fill test by Duval and Tweedie identified three missing studies, resulting in an adjusted ES of 0.35 (95% CI 0.04 to 0.66, $Q = 222.14$). These conflicting results can be attributed to the use of varying methods with distinct methodologies and underlying assumptions, leading to divergent outcomes. Each test has its own unique strengths and limitations, which ultimately influence the overall findings.

Discussion

The main goal of our systematic review and meta-analysis was to evaluate the overall impact of “imagination-to-learn” on the learning process while identifying potential moderating factors. In summary, the present meta-analysis demonstrated that the use of imagination had a significant impact in transfer scores, with a significant medium to high mean effect size ($g^+ = 0.51$). Additionally, retention scores also benefited were significantly, albeit with a medium effect size ($g^+ = 0.40$). This finding supports our hypothesis (Hypothesis 1) that students achieve better learning outcomes, particularly in terms of retention and transfer performance, when they incorporate imagination into their study practices. Furthermore, this finding aligns with previous research, including the meta-analysis conducted by Fiorella and Mayer (2015a), which reported an overall effect of imagination of $d = 0.65$. Clearly, imagination proves to be a powerful strategy for enhancing learning outcomes. It is, however, important to acknowledge presence of heterogeneity among the studies, signifying the need for further investigation into the specific conditions under which imagination is most effective or less in facilitating learning.

Our meta-analysis revealed that the effect of imagination was significantly moderated by learners' prior knowledge, specifically for transfer performance, and by learners' educational level for retention performance, which partially supports Hypothesis 2 and Hypothesis 4. More precisely, learners with high prior knowledge ($g^+=0.89$) benefited more from the imagination compared to those with low prior knowledge ($g^+=0.17$) in regard to transfer performance. Likewise, older learners ($g^+=0.43$) benefited more from imagination than younger learners ($g^+=-0.10$) concerning retention performance. This result aligns with previous findings by Cooper et al. (2001) and Ginns et al. (2003), which similarly demonstrated that imagination instructions were effective primarily for learners with higher prior knowledge. One plausible explanation, supported by previous research, is that more experienced learners can extract

greater advantages from the imagination technique because they can construct complex, higher-order schemas based on the foundational, lower-order schemas they already possess. In particular, learners with higher prior knowledge have developed sophisticated knowledge stored in long-term memory, enabling them to effectively integrate the interacting elements. Conversely, imagination instructions may be challenging or even impossible to apply for learners with lower prior knowledge, thereby rendering the imagination strategy less effective. This suggestion is consistent with the concept of the expertise reversal effect (Ben Chikha et al., 2023b; Castro-Alonso et al., 2021; Kalyuga, 2007; Kalyuga et al., 2003; Khacharem et al., 2015), which emphasizes that the most appropriate learning method depends critically on the learner's expertise level.

On the other hand, contrary to our hypotheses (3, 5, 6, 7), our analyses indicated that several potential moderating factors, namely learning domain, participants' educational level, medium, timing of imagination, and element interactivity level, did not show a significant moderation effect on the impact of imagination. Results from our moderator analyses indicated that the learning domain did not influence the effectiveness of imagination. Additionally, the participants' educational level was not a significant moderator, suggesting that imagination had a positive effect on learning regardless of the educational level. However, it is worth noting that most of the research on imagination-to-learn considered in this study was conducted with postsecondary students. Further empirical studies are needed to examine the robustness of the results with students in grades K-12. Furthermore, the medium in which the instructional materials were presented and the timing of imagination (e.g., during reading) were not significant moderators, suggesting that the imagination-to-learn technique has positive effects on learning regardless of the different types of instructional materials or the timing of instruction. However, further investigation is necessary to explore the impact of imagination when employed at different times or through alternative mediums, such as tablets (e.g., iPads).

Lastly, the element interactivity level did not play a moderating role on the imagination effect, contrary to previous findings. However, due to the limited number of studies examining imagination-to-learn with low element interactivity, caution is warranted when interpreting this result, and further research is needed to understand the relationship between element interactivity level and the effectiveness of imagination on learning outcomes.

Strengths, limitations, and implications for future research

The primary objective of this systematic review and meta-analysis is to assess the effectiveness of imagination on learning performances. The study demonstrates several strengths, including its comprehensive coverage of the existing literature, rigorous evaluation of study quality, and adherence to the PRISMA guidelines. However, there are some limitations that need to be addressed, and some methodological issues should be addressed in future studies in this field. First, it is important to note that our results are based on experiments comparing an imagination condition with a study condition, where learners were instructed to study the learning content only. We deliberately excluded the drawing condition from the experiments, wherein learners were instructed to visually represent (i.e., to draw) what they had learned (Leutner & Schmeck, 2014; Van Meter, 2013). While there are numerous learning strategies available to learners, as highlighted by generative learning theory (for an overview, see Fiorella & Mayer, 2016), the emphasis on drawing may be justified by its potential shared common aspects with imagination (Leopold & Mayer, 2015). It is worth noting that both imagination and learner-generated drawings are considered as pivotal tools in shaping both internal and external visualizations during the reading process (Cheng & Beal, 2019). These dynamic tools have demonstrated significant effectiveness in engaging learners in the transfer and retention of scientific texts (Leutner et al., 2009; Lin et al., 2017). Importantly, these two strategies engage learners in similar ways by promoting dual processing and building meaningful connections between words and images. For a more comprehensive grasp of the impact of

imagination, future research should include the “drawing condition” as a control condition for imagination. This inclusion would enhance our understanding of the unique contributions of imagination and drawing in the learning process. Second, although we made efforts to consider relevant moderator factors, it is important to recognise that there are numerous other potential factors that could influence the effectiveness of imagination. For example, there may be a difference between whether the content to be learned is explicitly presented in an animation (i.e., dynamic) or in a static format. Several meta-analyses have shown that dynamic visualisations are better instructional materials overall than static visualisations (Berney and Bétrancourt, 2016; Höffler and Leutner, 2007). However, from the cognitive load theory perspectives, dynamic formats can overload working memory due to their constant changes, which increases cognitive load and hinders effective learning (Khacharem et al., 2013b; Khacharem et al., 2014; Mayer et al., 2007; Schnotz & Rasch, 2005). Thus, it would be interesting to test the effects of imagination and presentation format of the material (e.g., animated or static) on learning performance to further investigate the relationship with relevant theories such as CLT or CTML. Another factor that should be investigated in future studies is the instructional time (e.g., short, moderate, or long) provided to learners, which plays a critical role in their ability to understand the learning material and achieve the desired learning outcomes (Mayer, 2014). It is reasonable to posit that increased exposure to educational materials could improve learning outcomes and promote positive attitudes toward the learning process. For example, Leopold and Mayer (2015) found a significant difference between groups in learning time, with the imagination group spending more time on presentation than the control group, resulting in better performance on transfer and retention tests.

Third, it is crucial to recognize the complexities associated with evaluating publication bias, as different methods employed in this regard have yielded inconsistent findings (Van Aert et al., 2019). Publication bias is a complex phenomenon influenced by various factors,

including selective reporting, study design, and publication practices. These factors may vary across different research fields or topics, contributing to inconsistencies in results obtained from different tests. Hence, it is important to interpret our findings with the usual amount of caution, considering these inherent complexities. Addressing these limitations and methodological considerations in future studies will contribute to a more comprehensive understanding of the effectiveness of imagination on learning performances.

Conclusion

The present study aimed to expand on the findings of Leopold and Mayer (2015a) by conducting a comprehensive systematic review and meta-analysis, providing a broader understanding of the impact of imagination on learning outcomes. The objective was to examine the overall effectiveness of learning through imagination compared to traditional studying approaches. The results showed a positive effect of imagination on learning for both transfer and retention, suggesting that learners who employed imagination-based learning exhibited improved performance compared to those who solely relied on studying. In addition, the study demonstrated that the effect of imagination was significantly moderated by learners' prior knowledge, particularly for transfer performance, and by learners' educational level for retention performance. More specifically, learners with high prior knowledge derived significantly greater benefits from imagination compared to those with low prior knowledge in regard to transfer performance. Similarly, older learners benefit significantly more from imagination than younger learners in terms of retention performance. These findings have practical and theoretical implications for educational research. By providing empirical support for CLT (Sweller, 1988) and the generative learning strategy (Fiorella & Mayer, 2016), the results emphasize the importance of incorporating imagination as a cognitive tool to enhance learning. However, it is important to note that further primary studies should be conducted in the future to validate and reinforce the findings of the present study. Additionally, while the

study encourages the use of imagination as a learning strategy, it also calls for further research in non-STEM domains and among a wider range of students in terms of age and cultural background. This will enable researchers to develop a more comprehensive understanding of the factors that moderate the effects of imagination on learning outcomes. Overall, the results of this study have significant implications for educators and instructional designers, suggesting that the incorporation of imagination as a learning technique can lead to improved learning outcomes.

PARTIE MÉTHODOLOGIQUE

Préambule

Les entraîneurs utilisent souvent des instructions verbales pour transmettre des stratégies tactiques, mais cette méthode ne garantit pas toujours une efficacité d'apprentissage. La nature abstraite de ces instructions et la réception souvent passive par les apprenants peuvent limiter leur efficacité, comme l'indique Kalyuga (2012). Les études récentes soulignent l'importance d'impliquer activement les apprenants dans leur processus d'apprentissage. Il est conseillé de favoriser une interaction dynamique avec le contenu enseigné, plutôt que de se contenter d'une écoute passive, pour améliorer l'assimilation des informations (Fiorella & Mayer, 2015). Une méthode efficace pour renforcer cet apprentissage consiste à encourager les apprenants à imaginer activement le contenu des instructions qu'ils reçoivent (i.e., principe de l'imagination ; Cooper et al., 2001 ; Ignatova et al., 2020 ; Sweller et al., 2011). L'objectif principal des travaux empiriques présentés dans les chapitres 3 à 6 de cette thèse est d'examiner l'impact de l'imagination sur l'acquisition de stratégies tactiques en basket-ball. Ils visent spécifiquement à évaluer comment l'efficacité de l'imagination varie en fonction du niveau d'expertise des joueurs et du moment des tests. Le Tableau 1 résume les questions de recherche abordées dans les chapitres 3 à 6.

Tableau 1. Récapitulatif des objectifs de chaque chapitre

Questions de recherche abordées	
Chapitre 3	Comment l'imagination des instructions tactiques de l'entraîneur influence-t-elle l'amélioration des performances d'apprentissage et la réduction de la charge cognitive ?
Chapitre 4	Quel effet le timing de présentation des scripts d'imagerie mentale (simultané ou séquentiel) a-t-il sur les résultats d'apprentissage ?
Chapitre 5	Comment l'incorporation des gestes de traçage à l'imagerie mentale peut-elle favoriser l'apprentissage des mouvements tactiques au basket-ball ?
Chapitre 6	Comment la modalité de présentation du script d'imagerie mentale (audio ou écrit) affecte-t-elle l'apprentissage tactique ?

Participants

Dans l'ensemble de toutes les études menées dans cette thèse, un total de 288 participants ont pris part à l'ensemble des expériences (Voir tableau 2). Parmi ces participants, 144 (Mage= 23.25 ; SD= 2.21) ont été identifiés comme des joueurs experts. Ils étaient membre de la troisième ligue française de basket-ball et ont été sélectionnés en fonction de critères spécifiques, tels que le nombre d'années d'entraînement (> 10 ans), le nombre d'heures (combien) et la fréquence d'entraînement hebdomadaire (combien), ainsi que leur participation régulière à des compétitions pendant la saison. Conformément à Swann et al. (2015), ces experts sélectionnés peuvent être considérés comme des joueurs semi-élites, dont le niveau de participation aux standards les plus élevés de leur sport (ex, dans les programmes de développement des talents, au niveau de deuxième classe ou inférieur, etc.) (voir tableau 3). D'autre part, 144 participants (Mage= 21.72 ; SD= 1.89) ont été désignés comme des joueurs novices. Ils étaient des étudiants universitaires sans expérience antérieure du basket-ball en club. Leur engagement dans ce sport se limitait à une participation occasionnelle à des activités récréatives ou à des cours d'éducation physique. Tous les participants ont choisi de participer volontairement aux différentes expériences, et le protocole de recherche a été approuvé par le comité d'éthique de l'université.

Tableau 2. Tableau récapitulatif du nombre des participants recrutés dans chaque étude

	Experts	Novices	Total
Chapitre 3	40 participants	40 participants	80 participants
Chapitre 4	50 participants (20 de chapitre 3 et 30 nouveaux)	50 participants (20 de chapitre 3 et 30 nouveaux)	60 participants
Chapitre 5	46 participants (20 de chapitre 3 et 26 nouveaux)	46 participants (20 de chapitre 3 et 26 nouveaux)	52 participants
Chapitre 6	88 participants (40 de chapitre 3 et 48 nouveaux)	88 participants (40 de chapitre 3 et 48 nouveaux)	96 participants
Total	144 participants	144 participants	288 participants

Tableau 3. Caractéristiques des participants experts impliqués dans cette thèse, selon la classification de (Swann et al., 2015)

Variable/score	1	2	3	4	
A. Standard de performance le plus élevé pour l'athlète	Niveau régional ou universitaire Semi-professionnel Division comprise dans le 4 ^{ème} quart	Talents en formation. Division comprise dans le 3 ^{ème} quart	Niveau national Sélection pour représenter la nation. Division comprise dans le 2 ^{ème} quart	Niveau international Division comprise dans 1 ^{er} quart (top)	Comparaison pour le même sport
B. Succès au plus haut niveau de l'athlète	Succès au niveau régional ou universitaire Semi-professionnel Ou succès dans le 3 ^{ème} /4 ^{ème} quart	Titres nationaux Ou succès dans le 2 ^{ème} /3 ^{ème} quart	Succès irréguliers au niveau international Ou succès dans le premier quart	Succès maintenu au niveau international	
C. Expérience au plus haut niveau de l'athlète	< 2ans	Entre 2 et 5ans	Entre 5 et 8ans	+ 8ans	
D. Compétitivité du sport dans le pays	Le sport fait partie du top dans le pays. Nation reconnue sportivement	Le sport fait partie du top 5-10 dans le pays. Nation moyennement reconnue sportivement	Le sport fait partie du top 5 dans le pays. Nation reconnue sportivement	Sport national. Nation reconnue sportivement	Comparaison entre les sports
E. Compétitivité globale su sport	Sport non olympique du monde sont limités à quelques pays. Peu d'audience TV.	Sport olympique occasionnel. Les championnats du monde sont limités à quelques pays. Peu d'audience TV.	Sport olympique récent, avec des compétitions internationales régulières. Audience TV globale moyenne.	Sport olympique avec des compétitions internationales majeures. Audience TV globale récurrente.	

Présentation du matériel d'apprentissage

Choix de l'activité « basketball »

Nous avons choisi le basketball comme discipline d'étude pour cette thèse en raison de ses caractéristiques uniques, propices à l'exploration de l'effet de l'imagination sur l'apprentissage tactique. La nature dynamique du basketball, caractérisée par sa rapidité et une

variété d'actions technico-tactiques telles que le tir, le dribble, la passe, le rebond et la défense, en fait un sport idéal pour les études rapportées dans cette thèse (Ben Chikha et al., 2022 ; Khacharem et al., 2019, 2020 ; Krause & Weigelt, 2022). De plus, l'interaction complexe entre les éléments de jeu – nécessitant une coordination et un jeu stratégique – offre un environnement riche pour analyser l'impact de l'imagination sur l'apprentissage tactique et la coordination entre les coéquipiers (García-Izquierdo et al., 2012).

Descriptif du matériel

Le matériel expérimental comprend un texte qui décrit le développement d'un système de jeu offensif en basketball. Ce système tactique complexe a été conçu en collaboration avec trois entraîneurs professionnels de basketball ($M_{\text{Âge}} = 43.67$; $M_{\text{Expérience}} = 12.67$ ans). L'originalité du système a été confirmée par une question spécifique posée après la phase de test, qui demandait aux participants d'évaluer leur connaissance préalable de la situation via une échelle de Likert de 9 points. Le texte est structuré en une introduction et quatre étapes principales. L'introduction spécifie le nombre de paragraphes qui décrivent le système de jeu, ainsi que les directives pour chaque condition expérimentale. Chaque paragraphe du texte examine une combinaison particulière mise en œuvre au sein du système de jeu. Pour répondre aux objectifs des études : deux versions du texte ont été développées : une version écrite en français, destinée à être lue sur un écran d'ordinateur, et une version audio, narrée par une voix masculine avec un accent français neutre.

Mesures

Variables de contrôle

Capacité d'imagerie mentale. Pour mesurer la capacité d'imagerie des participants, la version française du Vividness of Visual Imagery Questionnaire (VVIQ) (Santarpia et al., 2008) a été utilisée. Ce questionnaire se compose de 32 items et sert d'instrument d'auto-évaluation de la

netteté des images mentales. Chaque élément est noté sur une échelle de vivacité de 5 points, allant de (aucune image n'est visible) à 5 (l'image est parfaitement claire, aussi nette et précise qu'une perception réelle).

Temps consacré à la tâche. Pendant la phase d'apprentissage, la durée pendant laquelle chaque participant s'est engagé dans le matériel d'apprentissage a été enregistrée sous la catégorie « temps consacré à la tâche », mesurée en secondes.

Variables dépendantes

Précision du rappel. Les participants ont reçu une feuille contenant quatre terrains de basketball vierges. Ils étaient invités à reproduire avec la plus grande précision possible l'évolution du système de jeu, en dessinant correctement les actions et positions des joueurs à l'aide des symboles de flèches couramment utilisés au basketball pour schématiser le système de jeu (ex, une flèche en pointillé pour une simple passe et une flèche pleine pour le mouvement d'un joueur). La précision des représentations a été évaluée par deux évaluateurs indépendants qui ont comptabilisé le nombre total de réponses correctes et incorrectes. Un point était attribué pour chaque position ou action correctement indiquée, avec un score total possible allant de 0 à 36. Cette tâche de rappel a été mesurée lors des tests immédiats et différés.

Charge cognitive. Trois indicateurs ont été utilisés pour mesurer la charge cognitive associée à l'apprentissage du matériel pédagogique. Le premier indicateur mesurait l'effort mental investi (« Combien d'effort mental avez-vous investi dans l'apprentissage du matériel pédagogique ? » ; Paas, 1992). Le deuxième concernait la charge cognitive extrinsèque (« À quel point était-il difficile d'apprendre le matériel ? » ; Hasler et al., 2007), et le troisième mesurait la charge cognitive germane (« À quel point vous êtes-vous concentré pendant l'apprentissage ? » ; Cierniak et al., 2009). Chaque indicateur était évalué sur une échelle de 1 (très faible) à 9 (extrêmement élevée).

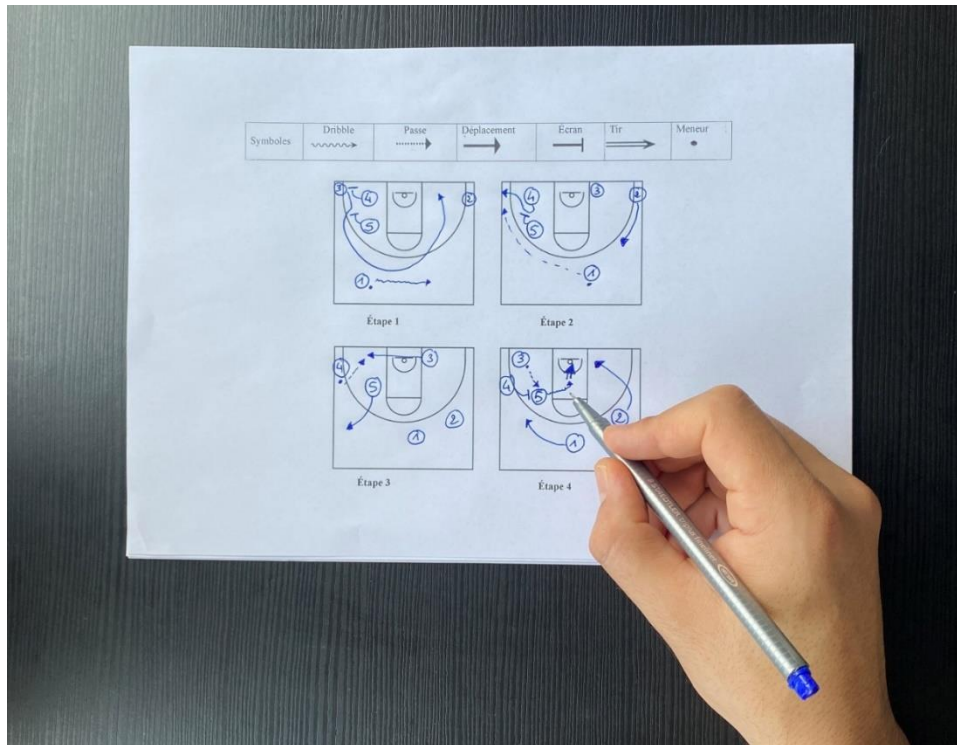


Figure 1. Exemple de tâche de rappel. Le participant reconstruit les éléments du système de jeu appris sur une feuille de papier, en utilisant des symboles pour représenter les actions de jeu et chiffres pour représenter les joueurs.

Procédure

Chaque expérience a été menée individuellement dans un laboratoire. Au début, les objectifs ont été clairement exposés aux participants, qui ont ensuite signé un formulaire de consentement éclairé et rempli un questionnaire démographique. Ils ont également complété la version française du (VVIQ) (Santarpia et al., 2008). Par la suite, les instructions d'apprentissage spécifiques à chaque condition d'étude leur ont été fournies. Ils ont reçu des directives détaillées pour étudier le matériel d'apprentissage sans contrainte de temps. Après l'étude, les participants ont évalué leur charge cognitive et ont passé un test de rappel. L'ensemble de l'expérience a duré environ 40 minutes. Une semaine plus tard, les mêmes participants ont été conviés à réaliser le même test de rappel (voir figure 2).

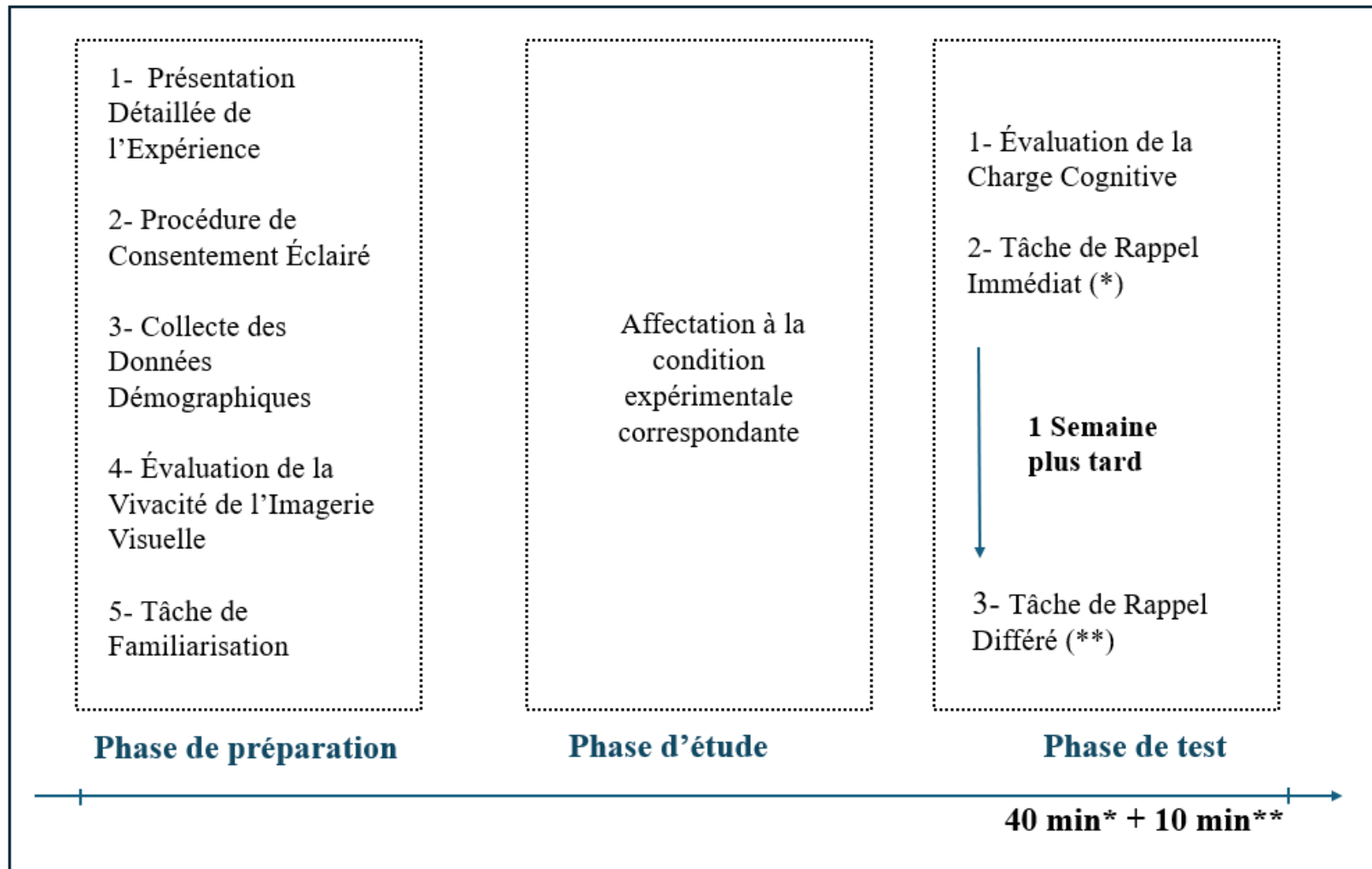


Figure 2.La procédure expérimentale

PARTIE EXPÉRIMENTALE

Chapitre 3 : Improving Tactical Learning by Imagination: Effects of Expertise and Time of Testing

Ce chapitre a fait l'objet d'un article publié :

Mguidich, H., Zoudji, B., & Khacharem, A. (2023). Improving Tactical Learning by Imagination: Effects of Expertise and Time of Testing. *The Journal of Experimental Education*, 1-15. <https://doi.org/10.1080/00220973.2023.2287456>

Improving Tactical Learning by Imagination: Effects of Expertise and Time of Testing⁴

Abstract

The imagination effect occurs when learners who imagine a procedure perform better on a subsequent test than learners who study it. The present study explored whether this effect is restricted to short-term learning or whether it also applies when learning is tested after a delay. Forty novices and forty experts learned about a basketball game system and were instructed to either listen and memorize (no-imagination condition) or imagine and memorize (imagination condition) the tactical instructions given orally. The results indicated that experts who imagined the material performed better in both immediate and delayed knowledge tests than experts who simply studied the same material, indicating a robust effect of the imagination in experts. However, the results showed that novices performed well in the immediate knowledge test under the no-imagination condition, but this effect was reversed in the delayed knowledge test, making imagination more beneficial. These findings indicate that the effectiveness of imagination over time depends on the level of expertise of the players.

Keywords: imagination, learning, tactics, cognitive load theory, expertise

⁴ Cet article de recherche a été publié sous le nom de : Mguidich, H., Zoudji, B., & Khacharem, A. (2023). Improving Tactical Learning by Imagination: Effects of Expertise and Time of Testing. *The Journal of Experimental Education*, 1-15. <https://doi.org/10.1080/00220973.2023.2287456>

Introduction

How to attack the opponent team? What action should be taken after receiving the ball? Where to position after losing the ball? Answering these questions depends on understanding tactical instructions given by the coach before or during practice. Game systems, whether simple or more complex, have two levels of organization: a structural organization consisting of components of the system (i.e., teammates, opponents, and ball) and a functional organization consisting of a sequence of actions performed by players (Khacharem et al., 2013a). However, players' comprehension of such systems may be challenged by the coach's instructional discourse that presents complex information or uses unfamiliar concepts. According to Khacharem et al. (2020), when listening to tactical instructions on how a basketball system works, inexperienced players may concentrate on integrating isolated information of play rather than creating a coherent mental representation of the whole system.

Prompting learners to imagine the instructional discourse is a promising support for understanding complex systems especially when pictures are not provided (i.e., imagination effect, Ginns et al., 2001; Sweller et al., 2011). However, according to the hypothesis of desirable difficulties (e.g., Bjork & Bjork, 2011), learning strategies that required extra cognitive resources might impede performance in the initial phase of learning but facilitate memory and retrieval when tested after a delay. Thus, assessing whether the imagination effect remains stable, across time and in learners with different levels of expertise, is a crucial question that needs to be addressed.

The imagination effect

In team sports, tactics and strategies play an important role in achieving success. From the perspective of coaching, tactics can be defined as the actions taken by a player, a group of players, or a team in response to the dynamically changing match situations. On the other hand,

strategies refer to pre-planned actions formulated in advance, where players and teams organize themselves based on carefully analyzed and readily accessible information (Gréhaigne & Godbout, 1995). Cognitive general imagery (Hall et al., 1998) is widely recognized as a highly effective technique to enhance strategies and tactical skills during actual game situations. For example, Munroe-Chandler et al. (2005) conducted a study that explored the impact of cognitive general imagery, using imagery scripts, on the performance of three soccer strategies in youth elite soccer players over a six-week period. The results showed a notable improvement in strategy execution during actual games. More recently, Frank et al. (2018) examined the influence of four-week team action imagery program (conducted through pictures and imagery scripts) on futsal players' mental representation of team level tactics. The results indicated that the group undergoing imagery training demonstrated mental representations that were more akin to those of experts after the intervention, in comparison to the control group that did not receive imagery training. However, despite the importance of these findings, it remains challenging to determine whether the improved performance was primarily a result of the mental imagery program or simply due to a “studying/learning” of the game tactics conveyed through the scripts.

Imagination, as defined by Sweller et al. (2011), involves mentally reproducing procedures or concepts. Additionally, it plays a crucial role in enabling learners to construct and generate the knowledge required for retention and transfer tasks. From a cognitive load perspective, the imagination effect occurs when learners achieve better results in learning procedures and concepts under imagination conditions compared to study conditions (Cooper et al., 2001, Leahy & Sweller, 2005, 2008, Tindall-Ford & Sweller, 2006). Cognitive load theory (CLT, Sweller, 2012; Sweller et al., 2011) is based on the human cognitive system and assumes that the capacity of working memory is very limited in capacity and duration when dealing with novel information. Accordingly, three types of cognitive load in working memory

are distinguished during learning: Intrinsic Cognitive Load (ICL; is caused by the complexity of the material as well as the interactivity of its elements (Ben Chikha et al., 2023a; Hazan-Liran & Miller, 2016); Extraneous Cognitive Load (ECL; is caused by an inappropriate design of learning material), and Germane Cognitive Load (GCL; results from active schema construction processes and is thus beneficial for learning) (Sweller, 2010).

The early research, primarily conducted in non-sporting areas, found that learning by imagining can be a beneficial instructional strategy, leading to improved learning results in several academic subjects (Fiorella & Mayer, 2015; Leopold et al., 2019). For example, Leutner et al. (2009) investigated the effects of imagination when learning a scientific text about the dipole character of water molecules. The results demonstrated that secondary school students who were asked to imagine each paragraph while reading achieved higher scores compared to their counterparts who were only asked to read the content without engaging in imagination. Similarly, Leahy and Sweller (2004) conducted a study with primary school teachers who were learning to read a contour map. The research revealed an imagination effect, indicating that teachers who were asked to imagine the procedure showed greater improvement in learning compared to those who were only asked to study the same procedure.

Cognitive load theory explains the imagination effect by assuming that information is more likely to be transferred and stored in long-term memory when learners are instructed to imagine the procedure or the concept. Leahy and Sweller (2008) indicated that imagination may act as a process of schemas automation and construction as learners can explicitly direct their limited Working Memory (WM) resources to all interacting elements, resulting in better use of available resources and higher productive ICL (Leahy & Sweller, 2008). As a result, imagining important elements might facilitate their transfer to long-term memory by increasing germane resources within working memory's available capacity (Ignatova et al., 2020). Moreover, according to the generative learning theory (Fiorella & Mayer 2016;

Wittrock, 1974), the imagination process enables learners to make better use of the dual-channel processing mechanism by allowing verbal information to be transformed into visual information through the generation of internal images. The process of converting a text into a mental image requires the learner to select the pertinent information from the text, organize it spatially in the mental image, and draw on prior knowledge to explain the meaning of the text and how it relates to the image (Fiorella & Mayer, 2016). In contrast, when learners solely read or listen to instructional material, they may experience an "illusion of understanding". This occurs because the information seems easy to process, resulting in superficial comprehension. However, this shallow processing can be misleading and lead to a false sense of understanding. Despite feeling familiar with the content at the moment, learners often struggle to establish strong connections in their long-term memory.

Nevertheless, a series of studies (see, Cooper et al., 2001; Ginns et al., 2003; Leahy & Sweller, 2004,2005) have noted prior knowledge as a moderator of imagination efficacy, suggesting that the imagination effect is more likely to occur in situations where learners have sufficiently developed schemas. According to such studies, inexperienced learners (i.e., novices), are unable to effectively use imagination technique and perform better with conventional study instructions (for review, see Mguidich et al., 2023a). For instance, Cooper et al. (2001) in a set of experiments examined the effectiveness of learning by imagining in purely cognitive domains by instructing learners to either imagine the performing steps of using a spreadsheet application or simply study worked examples. Learners in the imagination condition were asked to close their eyes or turn away after studying the worked example on the screen and try to imagine the performing steps of the procedure, while those in the study condition were asked to only study the same worked example. Overall, imagination instructions were found to be superior to study instructions, but only when participants already had some knowledge in the area. Specifically, novice learners with very limited experience benefited

more from studying the instructional material than from imagining, but as the learners become more experienced the advantage shifts from studying to imagining making the use of imagination techniques beneficial for more experienced learners. This phenomenon is referred to the expertise reversal, which states that instructional methods that are effective for inexperienced learners (novices) can reverse and become ineffective for experienced learners (experts), or vice versa (Chikha et al., 2022; Kalyuga, 2007; Kalyuga et al., 2003, Kyun et al., 2013). Accordingly, inexperienced learners -learners with little or no prior knowledge of the subject matter-, are likely to encounter greater challenges when trying to understand various components of the learning material. This is primarily because they cannot draw on previously acquired knowledge or schemas. As a result, study instructions that emphasize externally recorded information impose a lower load on WM than imagination instructions, making them more beneficial during the early stages of learning (Leahy & Sweller, 2008). However, for experienced learners, imagination can improve learning because these learners may have already acquired sufficient schematic knowledge that is present in long-term memory and is automated when imagining.

Even though it has long been assumed that imagination promotes active and deep processing of the learning material, only one study to our knowledge have directly examined the effect of imagination on students' long-term learning using delayed knowledge test (Leopold & Mayer, 2015). In this study, college students were instructed to either simply study (control group) or to mentally imagine (imagining group) the steps and structures of the human respiratory system while reading the text material. It was found that the imagining group scored better on a subsequent transfer test than the control group on both immediate (experiment 1) and delayed tests (experiment 2). These results suggest that when learners build connections between text and a mental image, they construct a deeper learning outcome with more retrieval routes, which consequently enhance performance over a time delay. However, it is important

to note that there is empirical evidence showing that effects that are observable in an immediate test can be inverted in a delayed test (Schweppe & Rummer, 2016; Ziegler & Stern, 2014). This phenomenon can be explained in the context of the desirable difficulties hypothesis (Bjork, 1994; Bjork & Bjork, 2011) which assumes that learning strategies that require additional cognitive resources may impair performance during the first learning phase but promote memory and recall in a later assessment (Bjork et al., 2013; van den Broek et al., 2014; Schweppe & Rummer, 2016). In other words, learning from situations in which the material is more actively processed can produce mental representations that are less likely to be forgotten and consequently remain in memory longer (Bjork & Bjork, 2011; Köhl, 2021).

The present study: research questions and hypotheses

The purpose of the current study was to investigate the effect of imagination on learning from a basketball game system. The main objective of this study was to ascertain whether the effectiveness of this strategy is modulated by the time of testing and learners' prior knowledge. Even though the effectiveness of imagination was explored through different levels of learners' expertise, this experiment was novel in several ways. First, the previous studies were methodologically limited by the range of prior knowledge of the learners. Most of them relied on measures that were not based on an empirically validated quantitative metric (see Ginns et al., 2012), such as class-wide mathematics grades or self-assessment of knowledge level in a particular domain, which is not an efficient measurement (e.g., Cooper et al. 2001; Ginns et al., 2003). Second, most of the available evidence for the imagination effect has been established across a wide range of instructional areas (e.g., science, technology, engineering, and mathematics) using visual/ spatial information (e.g., scientific text, graphs, and diagrams). Finally, in light of existing research, it remains unexplored whether the commonly observed negative effect of imagination on novices is influenced by the timing of testing and whether this phenomenon could potentially turn advantageous after a certain period. Hence, considering

these questions, the current study aimed to bridge the gap in the literature by examining the relative effects of imagination and prior knowledge on both short- and long-term learning.

Performance indicators were measured by immediate- and delayed tests of the learning content. A possible effect of expertise level was also considered, and cognitive load (i.e., mental effort, concentration, and perceived difficulty) was assessed in order to further evaluate the effects of the independent variables on the outcome measures. A basketball game system was chosen as the content for this study. It illustrates the movement of different game elements such as the players and the ball, during an attacking phase. The learning material is characterized as dynamic, relatively complex, and purely auditory (i.e., non-accessible to direct observation). Regarding learning outcomes, we hypothesized an interaction between the condition and expertise in the immediate phase. Specifically, we predicted that novice players would significantly benefit more from the no-imagination condition compared to the imagination condition by achieving higher recall performance (in term of accuracy and time), while expert players would show a greater advantage in the imagination condition (Hypothesis 1). Following the principles of desirable difficulties (Bjork, 2013; Bjork & Bjork, 2011), we hypothesized that for novice players, the relative benefits of the no-imagination condition over the imagination condition in the immediate phase would diminish or even reverse in the delayed phase. In contrast, expert players, with their extensive knowledge bases, were expected to demonstrate consistent performance patterns across both phases (Hypothesis 2). Additionally, we expected that novice players would perceive the content as more difficult (extraneous load), concentrate less during learning (germane load), and invest more mental effort when learning from the "imagination" condition compared to the "no-imagination" condition. Conversely, we anticipated the reverse pattern for expert players (Hypothesis 3).

Method

Participants

To determine an appropriate sample size, we explored effect sizes presented in previous research on presentation format and tactical learning (Ben Chikha et al., 2023b, Khacharem et al., 2020). We performed an a priori power analysis using G*Power 3.1.9.7 (Faul et al., 2020). An effect size of $f = 0.35$ with statistical power set (1- β -error probability) at 0.80 and an α -error probability of 0.05 requires a total sample size of 67. We recruited a larger sample of 80 French participants to allow for potential dropout or technical issues with data collection. As a result, a group of 40 expert male players and a group of 40 novice male basketball participants consented to take part in the study. The expert players ($Mage = 22.36$, $SD = 1.85$) competed in the third French basketball league and were selected based on specific criteria, including years of training ($M = 13.03$, $SD = 1.54$) and weekly training hours ($M = 9.22$, $SD = 0.76$). According to Swann et al. (2015), these selected experts can be categorized as semi-elite players, meaning their highest level of participation is below the highest possible standard in their sport (e.g., in talent development programs, at second-class level or below, etc.). The 40 novice players ($Mage = 21.85$, $SD = 1.75$) were university students with no prior experience playing basketball in a club. Their involvement with basketball was limited to occasional participation in recreational activities or physical education classes. All participants voluntarily participated in the experiment, and the study protocol was approved by the university ethics committee.

Participants were randomly assigned to either the imagination or no-imagination condition. There were 40 participants in the imagination condition (20 novices and 20 experts) and 40 participants in the no-imagination condition (20 novices and 20 experts).

Materials

The learning material consisted of a French audio-narration lesson that aimed to instruct players on the functioning of a specific basketball game situation. This game situation (developed in collaboration with 3 professional basketball coaches) included 5 attacker players numbered from one to five: point guard #1, shooting guard #2, small forward #3, power forward #4, center #5. The players executed a coherent tactical combination of play using 4 steps. Each step (i.e., corresponding to each new pass) included various actions of play like dribble, screen, movement without ball, etc. (in total 16 actions). The audio-narration contained 550 words and was delivered through male voice with a neutral French accent through loudspeakers.

Instructional conditions

Two instructional conditions were generated. In imagination condition participants were instructed to listen, and imagine the tactical instructions provided orally. Conversely, in the no-imagination condition, participants were instructed to solely listen to the same tactical instructions without engaging in imagining.

Measures

The measures consisted of (1) one imagery ability test, (2) time on task, (3) items assessing cognitive load associated with the learning material, and (4) a recall test (accuracy and time) to measure short- and long-term learning outcomes.

Mental imagery ability

To measure the participant's imagery ability, the French version (Santarpia et al., 2008) of the Vividness of Visual Imagery Questionnaire (VVIQ) was used. This questionnaire contains 32 items, which is a self-report instrument for evaluating how vividly individuals perform visual mental images. Each item is rated on a 5-point vividness scale, ranging from

(No image is visible) to 5 (the image is perfectly clear, as sharp and precise as a real-life perception).

Time on task

During the learning phase, the duration of participants' engagement with the learning material was recorded as “time on task” and measured in seconds.

Subjective ratings of Cognitive load

Three items were used to measure the cognitive load associated with learning the instructional material: one related to invested mental effort “How much mental effort did you invest in learning the instructional material?” (see Paas, 1992). One item was used to measure extrinsic cognitive load (ECL) “how difficult was it to learn the material” (Hasler et al., 2007), and one item was used to measure germane cognitive load (GCL) “how much did you concentrate during learning” (Cierniak et al., 2009). Each scale ranges from 1 to 9, with 1 as “very low” and 9 as “extremely high”.

Recall accuracy

Participants received a sheet of paper containing four empty basketball fields. They were instructed to reconstruct as accurately and precisely as possible the evolution of the game system, by indicating the correct action and position of the players. Specifically, participants were required to use arrow symbols usually used in basketball to illustrate the pattern of play (e.g., a dotted arrow indicated a simple pass, and a solid arrow indicated a player's movement). Two independent raters noted the total number of right and wrong answers that each participant provided when drawing the system. The degree of agreement between raters was assessed using Cohen's κ , and they showed high agreement ($\kappa = 0.92$). Disagreements between raters were resolved by consensus. One point was awarded for each correct position/action, otherwise, participants received zero points. The score could vary from

0 to 36. The recall time (sec.) was also measured for each participant in the immediate and delayed recall tests. The Cronbach's alpha reliability for the immediate recall test was 0.90 and 0.92 for the delayed recall test.

Procedure

The experiment was conducted individually in a laboratory setting. At the beginning of the experiment, participants signed an informed consent form and a demographic questionnaire. Next, they were asked to complete the French version of the vividness of visual imagery questionnaire (VVIQ; Santarpia et al., 2008). Then, they were given no time limits for studying the learning material with specific instruction according to their experimental condition (i.e., imagination vs no-imagination). Afterward, they filled in the cognitive-load questionnaire and performed the recall test. The experiment lasted about 40 min. One week later, the same participants were invited and were instructed to perform again the same recall test.

Data analysis

To analyze the control variable, time-on-task and cognitive load related to learning material, we performed a between-subjects analysis of variance (ANOVA) with 2 factors: expertise (novice vs. expert) $\times$ 2 condition (imagination vs.no-imagination). Moreover, for the analysis of learning outcomes, we conducted $2 \times 2 \times 2$ ANOVA with three factors: expertise (novice vs. expert) and condition (imagination vs.no-imagination) as between-subject factors, and time of testing (immediate vs. delayed) as within-subject factor. A significance level of 0.05 was used for all analyses, and partial eta squared (η^2) was reported as effect size measure for ANOVAs and Cohen's d for post-hoc comparisons. Whenever necessary, a post hoc comparison using Bonferroni test were used to determine the sources of any significant effects. Partial eta squared values of 0.01, 0.06 and 0.14 and Cohen's d values of 0.20, 0.50 and 0.80

represent small, moderate, and large effect sizes, respectively.

Results

Means and standard deviations are reported in Table 1.

Control variable

Before investigating the research questions, we investigated if the groups differed in mental imagery ability. For the mental imagery ability, the results revealed a non-significant effect of condition, $F(1, 76) = 0.769, p = .383, \eta_p^2 = .010$, and a no significant effect of expertise level, $F(1, 76) = 1.367, p = .246, \eta_p^2 = .018$. Expert players ($M = 4.07, SD = 0.39$) achieved equivalent VVIQ test results to novices ($M = 3.97, SD = 0.42$). There was also non-significant interaction between condition and expertise, $F(1, 76) = 0.216, p = .644, \eta_p^2 = .003$. These findings confirm that both groups were equivalent in their mental imagery ability.

Table 1. Means and standard deviations of Measurements

	Expert		Novice	
	Imagination	No- imagination	Imagination	No-imagination
Mental imagery	4.09 (0.37)	4.05 (0.40)	4.02 (0.38)	3.90 (0.45)
Time-on-task (sec.)	397.55 (52.62)	416.25 (58.72)	512.2 (53.42)	499.45 (50.77)
Cognitive load				
Mental effort	4.05 (1.52)	5.45 (1.90)	8.2 (0.85)	6.95 (1.32)
Concentration	6.60 (1.31)	4.50 (0.89)	6.85 (1.23)	7.95 (0.83)
Perceived difficulty	4.65 (1.19)	6.05 (1.37)	8.15 (0.81)	6.9 (1.34)
Immediate Phase				
Recall accuracy	32.1 (1.59)	27.45 (1.57)	13.25 (1.48)	16.15 (1.87)
Recall time	178.75 (20.52)	224.65 (29.28)	343.55 (59.43)	281.25 (53.13)
Delayed Phase				
Recall accuracy	25.95 (2.01)	19.85 (1.81)	8.7 (1.38)	6.3 (1.53)
Recall time	204.35 (36.67)	250.35 (40.88)	402.55 (32.92)	317.05 (37.02)

Time-on-task

Regarding the time-on-task, the results revealed a non-significant effect of condition, $F(1, 76) = 0.062, p = .805, \eta_p^2 = .008$, a significant effect of expertise, $F(1, 76) = 68.220, p < .001, \eta_p^2 = .473$, and a non-significant interaction between condition and expertise, $F(1, 76) = 1.724, p = .193, \eta_p^2 = .022$. The analysis showed that expert participants spent less time on learning the material ($M = 406.9, SD = 55.09$) compared to novice participants ($M = 505.83, SD = 51.84$).

Cognitive load associated with learning material

For the mental effort invested in learning the material, ANOVA revealed a non-significant effect of condition, $F(1, 76) = 0.069, p = .794, \eta_p^2 = .001$, a significant effect of expertise, $F(1, 76) = 97.788, p < .001, \eta_p^2 = .563$, indicating that novice participants invested more mental effort ($M = 7.58, SD = 1.25$) than expert participants ($M = 4.75, SD = 1.58$). The analysis revealed also a significant condition $\times$ expertise interaction, $F(1, 76) = 21.512, p < .001, \eta_p^2 = .221$. The post-hoc analysis revealed that novice participants invested less mental effort in the no-imagination condition than novices in the imagination condition ($p = .0144, d = 1.26$). However, expert participants invested less mental effort in the imagination condition than their counterparts in the no-imagination condition ($p = .005, d = 0.81$). Regarding the perceived difficulty, the analysis showed a non-significant effect of condition, $F(1, 76) = 0.081, p = .77, \eta_p^2 = .001$, a significant effect of expertise, $F(1, 76) = 67.932, p < .001, \eta_p^2 = .472$, indicating that novice participants perceived the content more difficult ($M = 7.53, SD = 1.26$) than expert participants ($M = 5.35, SD = 1.42$). There was also a significant condition $\times$ expertise interaction, $F(1, 76) = 25.211, p < .001, \eta_p^2 = .249$. The post hoc analysis revealed that novice participants perceived a low level of difficulty in the no-imagination condition than in the imagination condition ($p = .007, d = 1.13$). However, expert participants perceived a low level of difficulty in the imagination condition than experts in the imagination condition ($p =$

.002, $d = 1.09$). For the concentration, ANOVA revealed a significant effect of condition, $F(1, 76) = 4.255$, $p = 0.043$, $\eta_p^2 = .053$, indicating that participants concentrated more in the imagination condition ($M = 6.73$, $SD = 1.27$) than those in the no-imagination condition ($M = 6.23$, $SD = 0.86$). There was also a significant effect of expertise, $F(1, 76) = 58.255$, $p < .001$, $\eta_p^2 = .053$, indicating that novice participants ($M = 7.40$, $SD = 1.03$) concentrated more than expert participants ($M = 5.50$, $SD = 1.10$). Moreover, the analysis revealed a significant condition $\times$ expertise interaction, $F(1, 76) = 43.574$, $p < .001$, $\eta_p^2 = .434$. The post-hoc analysis revealed that novice participants concentrated more in the no-imagination condition ($M = 7.95$, $SD = 0.83$) than novices in the imagination condition ($M = 6.85$, $SD = 1.23$, $p = 0.117$, $d = 1.05$). However, expert participants concentrated more in the imagination condition ($M = 6.60$, $SD = 1.31$) than their counterparts in the no-imagination condition ($M = 4.50$, $SD = 0.89$, $p < .001$, $d = 1.86$).

These results demonstrated that novice players invested more mental effort, perceived more difficult, and concentrated less on learning the material in the imagination condition, whereas expert players invested less mental effort, concentrated more, and perceived less difficult to learn the material in the imagination condition.

Learning outcomes

The recall accuracy performance was analyzed using a repeated-measures ANOVA with the immediate and delayed recall test scores as the two-level within-subjects factor time of testing, condition, and expertise as between-subjects factors. The analysis revealed a significant effect of condition, $F(1, 76) = 86.97$, $p < .001$, $\eta_p^2 = .534$, indicating that participants in the imagination condition ($M = 20$, $SD = 1.62$) outperformed significantly those in the no-imagination condition ($M = 17.44$, $SD = 1.70$). There was also a significant effect of expertise, $F(1, 76) = 30.518$, $p < .001$, $\eta_p^2 = .976$, indicating that expert participants ($M = 26.34$, $SD = 1.75$) achieved higher recall scores than novice participants ($M = 11.10$, $SD = 1.57$). Moreover,

the analysis showed a significant effect of time, $F(1, 76) = 96.870, p < .001, \eta_p^2 = .927$, indicating that immediate recall performance ($M=22.23, SD=1.63, d=4.25$) was superior to delayed recall performance ($M= 15.20, SD=1.68$). This result indicates significant forgetting between the immediate and the delayed recall test. The analysis revealed also a significant condition $\times$ expertise interaction, $F(1, 76) = 104.77, p < .001, \eta_p^2 = .580$, a no significant time $\times$ expertise interaction, $F(1, 76) = 0.52, p = .475, \eta_p^2 = .007$, and a significant effect of time $\times$ condition interaction, $F(1, 76) = 55.70, p < .001, \eta_p^2 = .423$. Finally, there was a significant time $\times$ condition $\times$ expertise interaction, $F(1, 76) = 18.12, p < .001, \eta_p^2 = .193$. The post-hoc analysis revealed that novice participants in immediate testing performed better in the no-imagination condition ($M = 16.15, SD = 1.87, p < .001, d = 1.72$) than in the imagination condition ($M = 13.25, SD = 1.48$), whereas, in the delayed testing they performed better in the imagination condition ($M = 8.7, SD = 1.38$) than in the no-imagination condition ($M = 6.3, SD = 1.53, p < .001, d = 1.65$). These results indicated that the imagination condition compared to no-imagination condition led to less forgetting for novice participants. However, expert players performed better in the imagination condition ($M = 25.95, SD = 2.01$) than in the no-imagination condition in both immediate ($p < .001, d = 2.96$) and delayed testing ($p < .001, d = 3.70$).

For the recall time, similar to recall accuracy analysis, a repeated measures ANOVA was conducted with the within-subject factor time of testing (immediate vs. delayed) and the between-subject factors condition (imagination vs. no-imagination) and expertise (novice vs. expert). The analysis revealed a marginal effect of condition, $F(1, 76) = 3.626, p = .061, \eta_p^2 = .045$. There was a significant effect of expertise, $F(1, 76) = 274.455, p < .001, \eta_p^2 = .783$, with expert participants spending less time ($M = 214.53, SD = 31.84$) in the recall test compared to novices ($M = 336.10, SD = 45.63$). Moreover, the analysis revealed a significant effect of time, $F(1, 76) = 47.573, p < .001, \eta_p^2 = .385$, indicating that participants took more time to complete

the delayed recall test ($M = 293.58$, $SD = 40.59$, $d = 0.942$) compared to the immediate recall test ($M = 257.05$, $SD = 36.87$). Furthermore, there was a significant condition $\times$ expertise interaction, $F(1, 76) = 66.680$, $p < .001$, $\eta_p^2 = .467$, indicating that novice participants needed more time in the imagination condition than novices in the no-imagination condition ($p < .001$, $d = 1.41$), while, expert participants needed less time in the imagination condition compared to experts in the no-imagination condition ($p < .001$, $d = 1.32$). There was a no significant time $\times$ condition interaction, $F(1, 76) = 1.189$, $p = .279$, $\eta_p^2 = .015$, and a significant time $\times$ expertise interaction, $F(1, 76) = 4.217$, $p = .0435$, $\eta_p^2 = .053$, showing that both expert ($p < .001$, $d = 0.64$) and novice ($p < .001$, $d = 0.79$) participants needed more time in the immediate testing than in the delayed testing. Finally, there was no significant time $\times$ condition $\times$ expertise interaction, $F(1, 76) = 1.210$, $p = 0.274$, $\eta_p^2 = .016$. To examine the potential impact of mental imagery ability on learning performance, we conducted correlation analyses using Pearson's rank correlation coefficient. No significant correlations were found between mental imagery ability and immediate recall ($r = 0.14$, $p = 0.23$), delayed recall ($r = 0.16$, $p = 0.17$), time to immediate recall ($r = -0.08$, $p = 0.52$) and time to delayed recall ($r = -0.05$, $p = 0.69$).

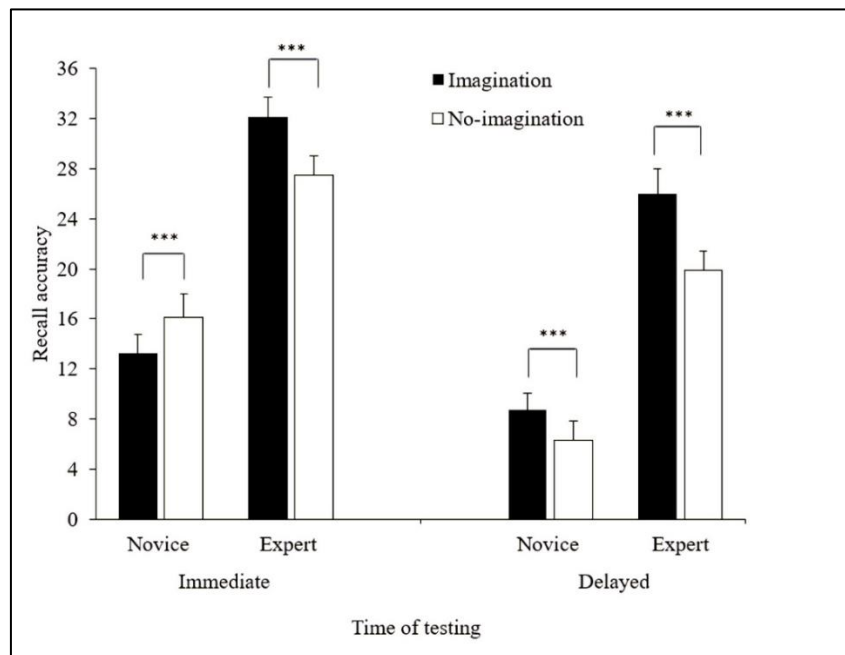


Figure 1. Recall Accuracy Score According to Experimental Condition, Expertise level, and Time of Testing

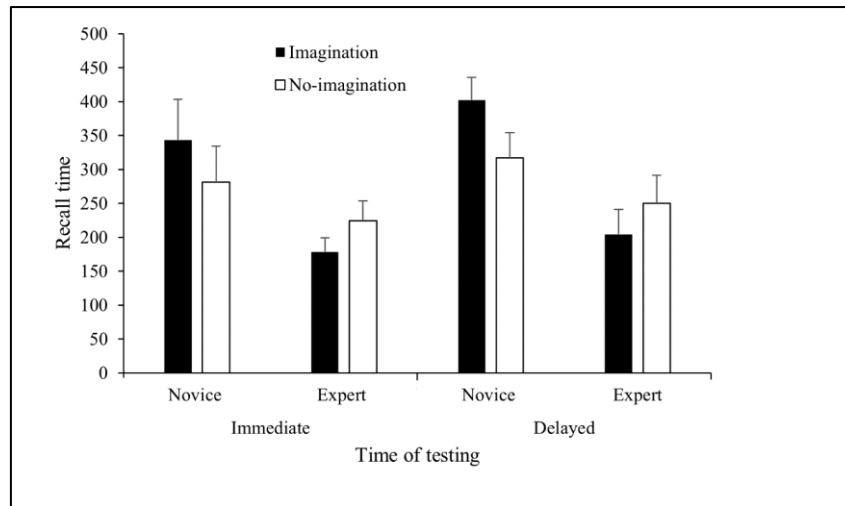


Figure 2. Recall Time According to Experimental Condition, Expertise level, and Time of Testing

Discussion

The present study aimed to examine the effect of imagination on learning from a basketball game system. A key part of this aim was to explore whether the effectiveness of this strategy is modulated by the time of testing and learners' prior knowledge. Overall, the results showed that expert learners exhibited lower cognitive load regardless of learning conditions, required less time to learn the material, performed better on both immediate and delayed recall, and required less time to recall information than novice learners. These findings are consistent with previous research on expertise, which has shown that experts have an advantage over non-experts in learning and recognizing sport-specific activities (Allard et al., 1980; Ben Chikha et al., 2023c; Gorman et al., 2011; Krause & Weigelt, 2022).

Concerning the immediate testing, in line with Hypothesis 1 the recall outcomes revealed an expertise reversal effect: Novice learners benefited more from the study instructions than from imagination instructions by achieving higher recall accuracy and less recall time, while expert learners benefited more from imagination rather than no-imagination instructions. These results are in accordance with previous studies carried out in non-sport related domains (e.g., Cooper et al., 2001; Ginns et al., 2003, Leahy & Sweller, 2004), demonstrating that for learners with low prior knowledge, study instructions tend to be more

effective than imagination instructions in the immediate testing. In the early stages of learning, novice learners must analyze the individual elements of the material, to develop a comprehensive understanding. This process allows them to uncover how these elements interact and construct new cognitive schemas for deeper comprehension of the subject matter (Leahy & Sweller, 2008; Lin et al., 2017). As learners progress and gain expertise in the field, they develop a deeper understanding of the relationships between the relevant elements within the game system (e.g., players' positions, motion, and trajectory) resulting in the formation of higher-order schemas (Gorman et al., 2012; Gorman et al., 2015). Consequently, experts benefit from using imagination as it enables them to efficiently process multiple items simultaneously in their working memory. This advantage is possible because the elements have become integrated into a schema, allowing for more effective cognitive processing (Ginns et al., 2003).

In line with Hypothesis 3, the subjective ratings of cognitive load provide further support for this interpretation, suggesting that cognitive load differences may explain the expertise reversal effect regarding the imagination effect. Novice learners who received imagination instructions found the content more challenging, had difficulty staying focused, and exerted more mental effort. Novices faced greater difficulties in the imagination condition, presumably leading them to expend additional effort and leaving fewer cognitive resources available for concentration, possibly resulting in more errors during the immediate phase. This was in contrast to expert learners, where the situation was reversed. On the other hand, experts benefited from imagination because they could seamlessly integrate the information into their existing mental structures, resulting in lower intrinsic cognitive load (ICL) and extraneous cognitive load (ECL), and higher germane cognitive load (GCL) (Ignatova et al., 2020).

Despite a decline in performance over time during delayed testing, the findings revealed an interesting pattern in learning performance among novice learners, indicating a positive

impact of imagination, which in line with Hypothesis 2. This suggests that the imagination condition led to a lower rate of forgetting compared to the no-imagination condition. These results align with previous research showing that conditions that challenge performance immediately after learning can actually be beneficial for long-term learning (known as “desirable difficulties”, e.g., Bjork, 2013; Bjork & Bjorek, 2020). Our findings indicate that the imagination condition encouraged deep and active processing of the learning material by novices, as they actively engaged in inferring and understanding the information. This depth of engagement appears to have resulted in knowledge that is less prone to forgetting (Bjork & Bjork, 2011; Kühl, 2021). This suggests that an important cognitive investment during the acquisition phase, reflected in high levels of cognitive load, facilitated knowledge consolidation in long-term memory and ultimately improved learning performance (Schweppe & Rummer, 2016; Pashler et al., 2007; Roediger & Karpicke, 2006). Interestingly, for expert learners, the timing of the test did not play a moderating role because of their well-established knowledge base, effective learning strategy and deep understanding of the subject matter. These factors collectively contribute to their superior recall performances, making them less affected by the passage of time between learning and testing.

Despite the important results reported in the present investigation, certain possible limitations of this study should be kept in mind when interpreting the results. One significant limitation of this study was its use of only a single item to represent each dimension of cognitive load. The use of single-item measures is often associated with concerns about unreliability, as it is difficult to calculate their reliability (Nagy, 2002; Nunnally & Bernstein, 1978). Such single-item measures may not possess the sensitivity necessary to detect nuanced differences or subtle variations within the construct. For greater precision in measurement, future studies could consider employing multiple items for each distinct type of cognitive load (Leppink et al., 2013). This multi-item approach would enable a more comprehensive assessment of the

subtleties of cognitive load and contribute to a deeper understanding of the phenomenon under study. Second, the recall test used to measure participant performance, primarily focuses on the cognitive process of translating verbal input into visual-spatial image. While this is valuable for assessing participants' ability to remember and represent the positions and actions of players, it may neglect other cognitive processes that may be involved in the task. To address this, future studies should consider incorporating a verbal recall test alongside the drawing test to better capture the participants' ability to accurately recall and verbally articulate the positions and actions of the players. Third, the ecological validity of this study is relatively low due to the sole use of verbal instructions as the learning material. To strengthen the validity of the results and provide a stronger connection to real-world scenarios, future studies should consider including visual aids such as drawings or pictures. Fourth, learners differed in their level of expertise; however, they presumably also differed in other variables, such as interest in the topic (Schiefele & Krapp, 1996; Ainley et al., 2002). Assessing and controlling for this variable would strengthen the study's conclusions by eliminating the possibility that the observed effects were solely due to interest and not expertise. Lastly, the post-test evaluations were conducted in a laboratory setting (i.e., paper pencil task to evaluate learning). Thus, it would be interesting to test the imagination effect in as more realistic task (i.e., on a basketball court) to further explore the applicability of the findings in real-life situations and ensure their practical relevance.

In conclusion, this study provides a significant contribution to the existing literature by being the first, to the best of our knowledge, to examine the impact of imagination in basketball. The findings shed light on a crucial aspect, specifically exploring the previously observed negative effect of imagination on novice learners, which is shown to be dependent on the time of testing. Furthermore, the study reveals that over time, the imagination effect can transform into an advantage for novices. Additionally, it highlights the advantages of using imagination

as a technique for expert learners in learning basketball tactics, regardless of the time of testing. In summary, this study concludes that the effectiveness of imagination is influenced not only by the time of testing but also by the learners' level of expertise. As a results, future studies should consider both these factors to gain valuable insights that enhance our understanding of teaching methods and the design of learning materials in the context of basketball and potentially in other domains as well.

Chapitre 4 : Does the Timing of Mental Imagery Scripts Affect the learning of playing Patterns?

Ce chapitre a fait l'objet d'un article soumis :

Mguidich, H., Zoudji, B., & Khacharem, A. (soumis). Does the Timing of Mental Imagery Scripts Affect the learning of playing Patterns? *Journal of Sports Sciences*

Does the Timing of Mental Imagery Scripts Affect the learning of playing Patterns?⁵

Abstract

Mental imagery is a well-known technique in sports psychology that is often used to improve learning and performance among athletes. While its benefits are widely acknowledged, the specific impact of the timing of mental imagery – whether it should be practiced simultaneously with auditory instruction or sequentially – still remains to be clarified. A total of 100 basketball players, categorized into experts (n=50) and novices (n=50), were randomly assigned to either a simultaneous imagery condition (listening and imagining concurrently) or a sequential imagery condition (listening followed by imagining). The study revealed an expertise reversal effect, with novices benefiting more from the simultaneous imagery condition, whereas experts benefited more from the sequential imagery condition. The study concludes that the timing of mental imagery scripts significantly affects learning outcomes in athletes, with the efficacy of imagery timing depending on the individual's level of expertise.

Keywords: mental imagery, expertise, tactical learning, basketball

⁵ Cet article de recherche a été soumis sous le nom de : Mguidich, H., Zoudji, B., & Khacharem, A. (soumis). Does the Timing of Mental Imagery Scripts Affect the learning of playing Patterns? *Journal of Sports Sciences*

Chapitre 5 : Combining Mental Imagery and Tracing Gestures to Enhance Basketball Tactical Learning

Ce chapitre a fait l'objet d'un article soumis :

Mguidich, H., Zoudji, B., & Khacharem, A. (soumis). Combining Mental Imagery and Tracing Gestures to Enhance Basketball Tactical Learning. *Journal of Applied Sport Psychology*.

Combining Mental Imagery and Tracing Gestures to Enhance Basketball Tactical Learning⁶

Abstract

Tracing gestures are hand movements designed to mimic or simulate specific actions. This study examined the effects of incorporating these gestures with mental imagery (dynamic imagery technique) versus using mental imagery alone (static imagery technique) on learning tactical movements in basketball. Additionally, it investigated how the effectiveness of these techniques varies with the players' levels of expertise (expert versus novice) and the timing of testing (immediate vs. delayed). The findings indicated that novices practicing dynamic mental imagery consistently outperformed those using only static imagery in both immediate and delayed tests (particularly in terms of recall accuracy and cognitive load). In contrast, while experts showed comparable benefits from both techniques in the immediate test, dynamic imagery was significantly more beneficial for them in the delayed test. These findings emphasize the significant role that the combination of mental imagery and tracing gestures plays in enhancing learning performances, with the effects varying depending on the time of testing and the level of expertise.

Keywords: mental imagery, tracing gestures, expertise, learning, tactics

⁶ Cet article de recherche a été soumis sous le nom de :
Mguidich, H., Zoudji, B., & Khacharem, A. (soumis). Combining Mental Imagery and Tracing Gestures to Enhance Basketball Tactical Learning. *Journal of Applied Sport Psychology*.

Chapitre 6 : Which modality is best for delivering an imagery script? Evidence for desirable difficulty effect

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Which modality is best for delivering an imagery script? Evidence for desirable difficulty effect⁷

Abstract

The aim of this study was to investigate the impact of a brief mental imagery task on immediate and delayed learning performance when participants were instructed about the functioning of a game system in basketball using either a written or an audio script. Expert (N =88) and novice (N= 88) basketball players were randomly assigned to one of four experimental conditions: (i) written script + no-imagery, (ii) audio script + imagery, (iii) written script + imagery, and (iv) written script + imagery. The main results showed that, regardless of the delivery modality of the script, novice participants derived benefited more from the no-imagery condition compared to the imagery condition in the immediate test. However, this advantage reversed in the delayed test one week following, indicating that mental imagery becomes more advantageous, particularly when delivered in written form. On the other hand, the results demonstrated that expert players performed better in both imagery conditions (in both immediate and delayed tests), particularly when the imagery was delivered in an audio format. These results suggest that the modality used to deliver a mental imagery script can significantly influence learning effectiveness, depending on the level of expertise.

Keywords: brief mental imagery, expertise, modality, learning, basketball tactics.

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Mguidich, H., Zoudji, B., & Khacharem, A. (2024). Which modality is best for delivering an imagery script? Evidence for desirable difficulty effect. *International Journal of Sport and Exercise Psychology*.
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Introduction

To what extent do two different modalities of delivering an imagery script impact one's ability to learn game plans? Learning game plans and strategies of play is crucial to successful performance in team sports, like basketball. Basketball players need to quickly and effectively process tactical information from coaches to form a coherent mental representation of game plans. Traditionally, game plans have been conveyed through direct verbal instructions (e.g., Khacharem, 2017) or tactic boards (e.g., Krause & Weigelt, 2022) before or during the practice session. However, recent developments in coaching methodologies have seen a shift towards incorporating mental imagery to enhance strategic skills (for an overview, see Westlund Stewart et al., 2012). To optimize the use of imagery, athletes can be guided with a script delivered either in written or audio format. Surprisingly, the instructional and cognitive effects of these two formats have not been sufficiently compared in a systematic manner. Hence, this study aims to assess the short-term and long-term effects of script formats on learning basketball game plans.

Imagery is a popular mental technique used by coaches and embraced by athletes to enhance performance. It describes “the creation and re-creation of an experience generated from memorial information, involving quasi-sensorial, quasi-perceptual, and quasi-affective characteristics, that is under the volitional control of the imager, and which may occur in the absence of the real stimulus antecedents normally associated with the actual experience” (Morris et al., 2005, p. 19). While sometimes used synonymously with mental practice, which includes various cognitive processes like self-talk and relaxation, imagery is distinct in its focus on reimagining experiences, extending beyond just motor skills to encompass mental rehearsals (Frank et al., 2021; Murphy & Martin, 2002). This technique allows athletes to reactivate and manipulate internal representations without actual sensory input. Athletes have reported that using imagery not only for refining motor skills (Callow et al., 2001; Cumming & Ste-Marie,

2001; Martin & Hall, 1995; Martin et al., 1999; Morris et al., 2005; Munroe-Chandler et al., 2012) but also for acquiring and executing high-level cognitive patterns, such as game tactics and strategies (i.e., cognitive general imagery; Munroe et al., 2000). Anecdotal evidence and numerous case studies highlight the widespread use of cognitive general imagery in practicing and enhancing game strategies across various sports, including canoe slalom races, skiing, football, wrestling, and basketball (for a comprehensive review, see Martin et al., 1999; Paivio, 1985). For instance, basketball players have been observed imaging strategies and game plans that they have worked on during the season (Cumming et al., 2004). However, despite its frequent use, limited knowledge exists regarding the impact of imagery on the comprehension of game plans and strategies – and the very few existing studies on this topic have yielded conflicting results. In a study conducted by Munroe-Chandler et al. (2005), a 6-week cognitive general imagery intervention was examined on young elite soccer players' imagery, but no significant effect on strategy performance was found (see also Guillot et al., 2009). In contrast, Fortes et al. (2018) discovered that young volleyball players benefited from an 8-week cognitive general imagery training program focused on passing decision-making (see also, Frank et al., 2018; Westlund Stewart & Hall, 2016). The mixed results in these studies may be attributed to challenges associated with measuring strategy performance, as strategies differ across sports and their execution in real-world situations can be difficult to control, complicating the measurement process (Westlund Stewart et al., 2012). Additionally, the use of group analysis (i.e., masking effect, Bryan, 1987; Shambrook & Bull, 1996), which overlook individual patterns and behaviors crucial for evaluating athletes' progress in real-world contexts, may contribute to the mixed effects.

Research in the field of applied psychology (Leopold & Mayer, 2015; Leutner et al., 2009) has also provided valuable insights into how learners benefit from imagining multiple interacting elements, such as those conveyed in complex game patterns. These studies have

introduced the concept of the “imagination effect”, which refers to the finding that imagining the behaviour of elements within a procedure or system improves learning performance compared to simply studying or reading the information. Consistent with cognitive load theory (Sweller et al., 1998; Sweller, 2020), actively engaging in cognitive processing through mental imagery facilitates the development and automation of cognitive schemas. In contrast to passive reading or studying, mental imagery allows learners to focus their working memory resources by selecting important components, organizing them into visual representations, and integrating them with prior knowledge (Fiorella & Mayer, 2015). This processing approach promotes deeper comprehension and encourages students to actively engage in the learning process (Fiorella & Mayer, 2016; Zhang & Fiorella, 2019). While numerous empirical studies have demonstrated the positive outcomes associated with imagination, the impact of this effect may depend on learners’ prior knowledge (Ginns et al., 2003; Leahy & Sweller, 2005; Mguidich et al., 2023a). This phenomenon, known as the expertise reversal effect (Khacharem et al., 2013a; Khacharem et al., 2020), indicates that the effectiveness of instructional support varies among learners with different levels of prior knowledge. According to this effect, proficient learners can derive advantages from imagination by constructing elaborate, higher-order schemas based on their already established simple, lower-order schemas. Conversely, novice learners may need to understand basic concepts before they can develop relatively complex schemas. Without fundamental schematic knowledge, they may not be able to fully benefit from imagery. Nevertheless, as novices learn, their mental representations evolve into more complex hierarchical structures through imagery exposure (Frank et al., 2013). Such developmental changes indicate functional alterations in long-term memory (Schack & Ritter, 2013). Consequently, imagery plays significant role in the perceptual-cognitive organization of actions during early stages of learning, thereby internally stimulating learning (Frank et al., 2023; Frank & Schack 2017).

Previous research has demonstrated that imagery can be facilitated through two main delivery modalities: reading or listening to an imagery script (e.g., Cooley et al., 2013). Listening to spoken words engages the audio modality, while reading written or on-screen words involves the visual modality. Despite these findings, there has been a lack of comprehensive investigation into the comparative effectiveness of these two delivery modalities. Holmes and Collins (2001) also emphasized the often-overlooked significance of the imagery script modality. Only one empirical study (Smith & Holmes, 2004) has compared the effectiveness of these two modalities in a motor skill task, specifically golf putting performance. The results revealed that the audio group performed significantly better than the written group, suggesting that the delivery format of an imagery intervention can significantly impact its effectiveness. Although the study did not measure brain activity, it was suggested that reading a written script may not provide the same level of access to the cortical structures required for task preparation and execution compared to using video or audiotape, which involve more direct and extensive multisensory engagement (Farah, 2000; Zatorre et al., 1996). Feedback obtained from the manipulation checks and participants' diaries also identified a significant issue regarding functional equivalence. Participants who used a written script reported experiencing timing issues while imagining the task, despite being the ones who had provided the content of the script themselves. Moreover, from a cognitive load perspective (Sweller et al., 1998; Sweller, 2020) it can be suggested that the audio script offers an advantage by enabling learners to directly and simultaneously imagine the movement or game pattern, resulting in reduced processing demands. In contrast, a written script requires learners to repeatedly inspect and reinspect the text, which can cause them to lose focus or disengage from the imagery activity.

The effectiveness of imagery has typically been assessed immediately after learning (Mayer, 2009), with relatively less attention given to delayed knowledge tests (e.g., Frank et

al., 2018; Lepold & Mayer, 2015; Leutner et al., 2009). However, the timing of testing plays a crucial role as empirical evidence suggests that effects observed in immediate learning tests may be reversed when tested after a delay (H'mida et al., 2022; Roediger & Karpicke, 2006; Schweppe & Rummer, 2016). For example, Schweppe & Rummer (2016) investigated the role of material modality (written vs audio) in supporting long-term learning. In this study, retention and transfer performance were tested immediately after the learning phase and one week later. The results showed that learners benefited more from the auditory modality. However, the written modality was more beneficial when learning was tested after one week, indicating that it functions as a desired difficulties that promotes long-term learning. This moderating role of timing can be explained within the framework of desirable difficulties (Bjork & Bjork, 2011). Desirable difficulties encompass various instructional manipulations aimed at enhancing learning outcomes. These manipulations include varying learning conditions, spacing study or practice sessions, reducing feedback, introducing contextual interference (e.g., interleaving practice), and promoting active processing, such as encouraging learners to generate or infer information (Bjork, 1994). Mental imagery, which involves generating mental images based on textual information, is a cognitively demanding process that aligns closely with the concept of desirable difficulties. During mental imagery tasks, students often face challenges as they need to mentally infer essential information that is not directly available, resulting in a significant cognitive load, particularly for novice learners. However, engaging in mental imagery promotes deeper interaction with the learning material, leading to stronger memory traces and the formation of more effective retrieval cues. This, in turn, facilitates the reactivation of previously learned information, especially when tested after a delay (Bjork & Bjork, 2011; Bjork, 1994; Köhl, 2021). Therefore, mental imagery serves not only as an instructional strategy fostering challenging and beneficial learning experiences but also plays a pivotal role in shaping action-related cognition. One of the key reasons for the effectiveness

of imagery lies in its alignment with motor simulation theory, which has gained considerable support (Jeannerod, 1994, 2001). At the core of this theory is the concept of functional equivalence between imagined action to actual actions, as they share similar processes and rely on the same action representation (Finke, 1979; Jeannerod, 1994, 1995). More recently, Bach et al. (2022) suggest that when using imagery, people focus on the desired outcomes they want to achieve rather than performing a simulation that involves the motor system.

The present study: Research questions and hypotheses

The aim of the present study was to investigate the effects of a brief mental imagery task on immediate and delayed learning outcome performance when participants were guided through a written or an audio script describing a game tactic in basketball. We assessed learning outcomes using recall accuracy immediately after the learning phase (referred to as the immediate phase) and one week later (referred to as the delayed phase). Additionally, we collected subjective assessments of cognitive load (i.e., mental effort, concentration, and perceived difficulty). To overcome limitations associated with real-world motor performance and minimize the masking effect, an educational-psychological approach was adopted. This involved a brief intervention to investigate the short-term and long-term effects of script modality delivery while controlling for potential confounding factors and constraints related to real-context motor execution (as discussed earlier).

This current study introduces novel perspectives in comparison to previous studies. Firstly, prior investigations mainly focused on imagery in specific motor tasks like golf putting, limiting our understanding of its application in complex game plans (Smith & Holmes, 2004). By expanding the investigation, this study contributes to a comprehensive understanding of imagery's effectiveness in diverse contexts. Secondly, while prior research only included novice or amateur participants, this study goes a step further by incorporating experienced players. This inclusion allows for a more comprehensive examination of the benefits and

effectiveness of imagery techniques for players with varied expertise levels. Lastly, in line with the desirable difficulties hypothesis, incorporating a delay in testing becomes crucial. Immediate benefits of imagery may not directly translate to enhanced retention or improvement in long-term learning conditions. By including both immediate and delayed recall tests, this study provides insights into the temporal dynamics of learning outcomes and the potential advantages of delayed testing scenarios.

In relation to the cognitive load required to process the learning material, we expected novice participants to encounter higher difficulty, lower concentration, and to invest greater mental effort when learning with imagery compared to no-imagery conditions. In contrast, expert players were anticipated to exhibit the opposite pattern: lower difficulty, higher concentration, and reduced mental effort, particularly when using the audio script (Hypothesis 1). This prediction aligns with cognitive load theory (Sweller, 2020), which posits that learners need to manipulate material in their working memory when imagining. Due to the limitations of working memory, novices may find it challenging to process unfamiliar material in working memory, requiring extra effort, and leaving fewer cognitive resources for concentration. However, experts who have previously developed mental cognitive schemas enabling efficient working memory processing may experience less difficulty, higher concentration, and reduced mental effort under imagery conditions. Their existing mental structures facilitate streamlined information processing and efficient allocation of cognitive resources.

Consistent with previous research on the expertise reversal effect (Kalyuga, 2007; Mguidich et al., 2023b) which highlighted the central role of knowledge in learning processes, we hypothesised that during the immediate testing phase, novice participants would derive fewer benefits from imagery conditions compared to no-imagery conditions. Conversely expert players were predicted to benefit more from imagery conditions, especially when using the audio script, due to their available knowledge structures acquired through deliberate practice (Hypothesis 2).

In the delayed testing phase, we predicted that novice participants would derive greater benefits from imagery conditions, especially when using a written script. Conversely, expert players were expected to maintain similar performance patterns observed in the immediate phase (Hypothesis 3). This assumption aligns with the desirable difficulty hypothesis (e.g., Bjork, 2013; Bjork & Bjork, 2011), which suggests that conditions involving more active processing may lead to knowledge representation that is less prone to forgetting and persists longer when measured with a delayed knowledge test.

Method

Participants and design

Based on a priori power analysis using G*Power 3.1.9.7 (Faul et al., 2020), we used analysis of variance (ANOVA) to examine fixed effects, special, main effects, and interactions, and the following input parameters: An effect size of 0.25 ($f = 3.92$), an α -error probability of 0.05, a power ($1-\beta$ -error probability) of 80%. Based on the analysis, a total sample size of 128 participants was considered necessary for this study. Therefore, we recruited 176 participants ($Mage = 22.81$, $SD = 1.92$), who had two different levels of expertise. The first group consisted of 88 expert players ($Mage = 23.44$, $SD = 1.86$) with more than 10 years of experience in team basketball ($Mage = 13.25$, $SD = 1.50$). The second group consisted of 88 university students ($Mage = 22.19$, $SD = 1.78$) who had never played basketball or any other team ball sport in a club and only occasionally participated in recreational activities or physical education classes. All participants voluntarily participated in the experiment, and the study was approved by the university ethics committee.

The experiment utilized a $2 \times 2 \times 2$ between-subjects design, including the factors of expertise (novice vs. expert), script modality (audio vs. written), and condition (imagery vs. no-imagery). Participants were assigned to one of four conditions: written script + no-imagery

($N = 22$ experts vs 22 novices), audio script + no-imagery ($N = 22$ experts vs 22 novices), written script + imagery instructions ($N = 22$ experts vs 22 novices), audio script + imagery instructions ($N = 22$ experts vs 22 novices).

Materials

An imagery script for a basketball game plan was developed collaboratively by three licensed basketball coaches (*Mean Age* = 43.67 years; *SD* = 4.16, *Mean Experience* = 12.67; *SD* = 0.58). In crafting the structure of the imagery script, the team adhered closely to the established guidelines proposed by Williams et al. (2013). These guidelines emphasize the importance of the five Ws—Who, Where and When, Why, and What—to maximize the script's effectiveness and ensure it is well-tailored to its intended purpose. The script offers comprehensive instructions for a game plan involving five players, each assigned to a specific position and corresponding role: playmaker #1, fullback #2, winger #3, power forward #4, and pivot #5. The game plan consists of a strategic combination of 16 actions organized into four phases. These actions encompass various elements, including passes, movement, dribbling, and other actions. Two versions of the imagery script were created: a written version presented on a computer screen and an audio-narration version delivered through digitized speech by a male voice with a neutral French accent.

Measures

Mental imagery ability, mental imagery and time on task were assessed as control variables. The dependent variable was the recall accuracy score, which was assessed in both immediate and delayed post-tests. In addition, subjective ratings of cognitive load were collected immediately after the learning phase.

Mental imagery ability was assessed using the French version (Santapira et al., 2008) of the Vividness of Visual Imagery Questionnaire version (VVIQ-2; Marks, 1995). This

questionnaire consists of 32 items self-report instrument for evaluating how vividly individuals perform visual mental images, each rated on a 5-point vividness scale ranging from (*No image is visible*) to 5 (*the image is perfectly clear, as sharp and precise as a real-life perception*).

In order to determine whether participants followed the instructions during the study phase, we administered a questionnaire adapted from Leopold and Mayer (2015) (Cronbach's $\alpha = .85$). All self-report scales were 5-point scales ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The items were "I mentally imagined how the game scene unfolded," "I formed mental pictures of all the players and actions in order to understand the game system," "I created mental pictures about the game system," and "I tried to understand the structure and flow of the game system through mental imagery."

The duration of participants' engagement with the learning material was recorded as time on task, measured in seconds during the learning phase. Cognitive load associated with learning material was assessed using three subjective cognitive load questions: a mental effort (Paas, 1992), extrinsic cognitive load (ECL) and germane cognitive load (GCL) (Cierniak et al., 2009). Each scale ranges from 1 to 9, with 1 as "*very low*" and 9 as "*extremely high*". The statement of the mental effort scale was "How much mental effort did you invest in learning the instructional material?". For the ECL the statement was "how difficult it was to learn the material". For the GCL the statement was "how much did you concentrate during learning".

The assessment of learning outcomes was conducted through a recall test, which was administered twice: immediately after learning and approximately one week later. Participants were given a sheet of paper containing four empty basketball diagrams. They were instructed to reconstruct the respective game phase within each specific diagram by indicating the correct action and position of the players using arrow symbols commonly used in basketball (e.g., a dotted arrow indicated a simple pass, a solid arrow indicated player movement). Two independent raters scored the participants' responses, awarding one point for each correct

answer and zero points for incorrect answers. Cohen's κ statistics were used to evaluate the degree of agreement between the raters, demonstrating a high degree of agreement ($\kappa = 0.93$). Any discrepancies between raters were resolved through discussion. The recall score ranged from 0 to 36.

Procedure

As illustrated in Figure 2, the experimental procedure consisted of three phases.

Preparation phase: Upon arrival, participants were briefed about the experiment's objectives. They provided informed consent and completed a demographic questionnaire regarding personal information. Subsequently, they filled out the Vividness of Visual Imagery Questionnaire (VVIQ; Santarpia et al., 2008). Finally, participants were familiarized with the learning instructions pertinent to their respective study condition.

Study phase: Participants were randomly assigned to one of four experimental conditions (no time limits were imposed on studying the learning material):

- In the “audio imagery” condition, participants were instructed to listen and mentally imagine the orally presented tactical scene.
- In the “audio no-imagery” condition, participants were instructed to solely listen to the same tactical scene without engaging in mental imagery.
- In the “written imagery” condition, participants were instructed to read and mentally imagine the visually presented tactical scene.
- In the “written no-imagery” condition, participants were instructed to solely read the same tactical scene without engaging in mental imagery.

Test Phase: immediately after studying the learning material, participants were first asked to complete a self-report mental imagery questionnaire and a cognitive load

questionnaire. Subsequently, they performed an immediate recall test. After one week, participants returned for the delayed recall test, which required them to reconstruct the basketball situation they had previously learned, without any visual presentation provided. On average, participants spent approximately 30-40 min in the first session and 10 min in the second session (Figure 1).

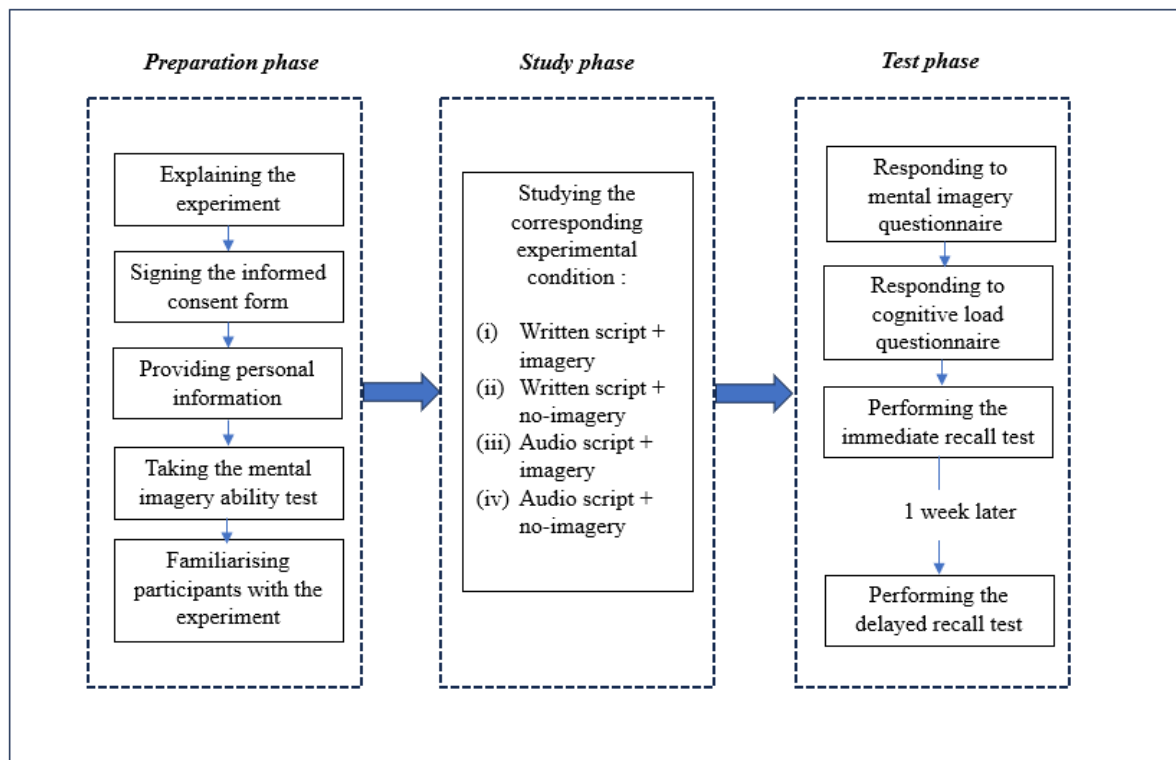


Figure 1. Experimental Procedure

Data analysis

To ensure that the assumptions necessary for parametric tests were not violated, both Levene's test for homoscedasticity and Kolmogorov-Smirnov's test for normality of distribution were employed. To analyze the data, we performed a between-subjects analysis of variance (ANOVA) with a 2 (expertise: novice and expert) $\times$ 2 (condition: imagery and no-imagery) $\times$ 2 (script modality: audio and written) factorial design. A significance level of 0.05 was used for all analyses, and partial eta squared (η_p^2) was reported as effect size measure for

ANOVAs and Cohen's *d* for post-hoc comparisons. Partial eta squared values of 0.01, 0.06 and 0.14 and Cohen's *d* values of 0.20, 0.50 and 0.80 represent small, moderate, and large effect sizes, respectively. Whenever necessary, a posteriori comparison using Bonferroni correction for Type I error was used to determine the source of any significant effects.

Results

Table 1. Mean and Standard Deviations for Mental Imagery Ability and the Cognitive Load Associated to Learning as Function of Experimental Conditions and Expertise Level

	Audio script		Written script	
	Imagery	No-imagery	Imagery	No-imagery
Novice				
Mental imagery ability	4.12 (0.45)	3.97 (0.45)	4.08 (0.56)	4.01 (0.42)
Mental effort (1-9)	8.27 (0.83)	6.91 (1.27)	7.54 (0.86)	7.05 (1.13)
Concentration (1-9)	6.82 (1.15)	7.91 (0.81)	6.77 (1.29)	8.45 (0.67)
Perceived difficulty (1-9)	8.23 (0.75)	6.95 (1.29)	7.82 (0.96)	6.59 (0.59)
Expert				
Mental imagery ability	4.18 (0.41)	4.02 (0.46)	4.16 (0.51)	4.05 (0.40)
Mental effort (1-9)	4.09 (1.63)	5.5 (1.19)	5.59 (0.85)	5.32 (0.89)
Concentration (1-9)	6.55 (1.22)	4.45 (0.91)	5.54 (1.14)	5.82 (1.59)
Perceived difficulty (1-9)	4.55 (1.43)	6.09 (1.38)	5.86 (1.13)	5.63 (1.02)

Control variables

Before testing the hypotheses, we analyzed whether the experimental groups differed in mental imagery ability and time on task. There was no significant group difference with respect to mental imagery ability, (all $p < 0.05$). The vividness ratings were reliable (Cronbach's alpha interrater reliability = .88). The top line of Table 1 shows the mean mental imagery ability (and standard deviation) for each group. The analysis of the mental imagery questionnaires aimed to assess participants' adherence to study phase instructions. Results indicated a significant effect of condition, $F(1, 168) = 148.46$, $p < .001$, $\eta_p^2 = .98$. Subsequent post-hoc analysis revealed that participants in the imagery conditions ($M = 4.88$, $SD = 0.20$)

reported significantly higher levels of mental imagery activity during learning compared to those in the no-imagery conditions ($M = 1.14$, $SD = 0.22$). These findings served as a manipulation check for our study. For the time on task, the analysis revealed only a significant effect of expertise $F(1, 168) = 160.03$, $p < .001$, $\eta_p^2 = .489$, with expert participants spending less time on task learning ($M = 405.59$, $SD = 53.63$) than novice participants ($M = 505.93$, $SD = 53.63$).

Hypothesis 1: There will be an interaction between modality, expertise and condition on the subjective ratings of cognitive load

Hypothesis 1 was investigated with three-factorial ANOVAs with modality (audio vs. written), expertise (novice vs expert) and condition (imagery vs. no-imagery) as independent variables, mental effort, difficulty, and concentration as dependent variables. Means and standard deviations are reported in Table 1. The results showed no significant effects of modality on mental effort ($F(1, 168) = 1.175$, $p = .280$, $\eta_p^2 = .007$), difficulty ($F(1, 168) = 0.020$, $p = .887$, $\eta_p^2 = .001$), or concentration ($F(1, 168) = 1.610$, $p = 0.206$, $\eta_p^2 = .009$). Concerning expertise, significant effects were found for mental effort, $F(1, 168) = 190.983$, $p < .001$, $\eta_p^2 = .532$, difficulty, $F(1, 168) = 136.297$, $p < .001$, $\eta_p^2 = .448$, and concentration, $F(1, 168) = 124.372$, $p < .001$, $\eta_p^2 = .425$. Expert participants reported lower perceived difficulty ($p < .001$, $d = 1.54$), invested less mental effort ($p < .001$, $d = 1.87$), and exhibited higher levels of concentration ($p < .001$, $d = 1.42$), compared to novice participants. The condition did not significantly affect mental effort ($F(1, 168) = 1.175$, $p = .280$, $\eta_p^2 = .007$), difficulty ($F(1, 168) = 3.426$, $p = 0.066$, $\eta_p^2 = .011$), or concentration ($F(1, 168) = 1.967$, $p = 0.163$, $\eta_p^2 = .012$). The interaction between modality and expertise was significant for mental effort ($p < .05$, $\eta_p^2 = .004$) and difficulty ($p < .05$, $\eta_p^2 = .038$), but not for concentration ($F(1, 152) = 1.160$, $p = 0.690$, $\eta_p^2 = .001$). The interaction between modality and condition was significant for difficulty ($p = 0.008$, $\eta_p^2 = .042$) and concentration ($p < .05$, $\eta_p^2 = .101$), but not for mental effort ($F(1, 168)$

= 1.487, $p = 0.224$, $\eta_p^2 = .009$). The expertise and condition interaction significantly affected mental effort ($p < .001$, $\eta_p^2 = .103$), difficulty ($p < .001$, $\eta_p^2 = .164$), and concentration ($p < .001$, $\eta_p^2 = .198$). Finally, a significant modality $\times$ expertise $\times$ condition interaction was found for mental effort ($p < 0.001$, $\eta_p^2 = .079$), difficulty ($p < 0.01$, $\eta_p^2 = 0.046$), and concentration ($p < 0.01$, $\eta_p^2 = .038$). Post-hoc analysis revealed that in the audio no-imagery condition, novices invested less effort ($p = 0.002$, $d = 1.27$), found the content less difficult ($p = 0.003$, $d = 1.21$), and exhibited higher levels of concentration ($p = 0.005$, $d = 1.10$) than novices in the audio-imagery condition. In the written no-imagery condition, novices invested the same mental effort ($p = 1.00$, $d = 0.49$), found the content less difficult ($p = 0.005$, $d = 1.54$), and showed higher concentration ($p < .001$, $d = 1.63$). However, expert participants in the audio imagery condition invested less mental effort, found the content less difficult ($p < .001$, $d = 1.41$), and exhibited higher levels of concentration compared experts in the audio no-imagery condition. No-significant effects were found for mental effort ($p = 1.00$, $d = 0.31$), difficulty ($p = 1.00$, $d = 0.21$) and concentration ($p = 1.00$, $d = 0.22$) between the written imagery and written no-imagery conditions for expert participants.

Hypothesis 2: There will be an interaction between modality, expertise and condition on the immediate recall performance

Hypothesis 2 was investigated also with three-factorial ANOVAs with modality (audio vs. written), expertise (novice vs expert) and condition (imagery vs. no-imagery) as independent variables, and immediate recall accuracy as dependent variables. For the immediate recall test, ANOVA demonstrated main effects for modality, $F(1, 168) = 9.19$, $p < .01$, $\eta_p^2 = .051$, expertise $F(1, 168) = 319.241$, $p < .001$, $\eta_p^2 = .95$, but no significant effect of condition, $F(1, 168) = 1.65$, $p = 0.200$, $\eta_p^2 = .010$. The written modality yielded higher recall scores ($M = 23.045$, $SD = 6.77$) compared to the audio modality ($M = 22.30$, $SD = 8.01$), and expert participants ($M = 29.66$, $SD = 2.35$) outperformed novice participants ($M = 15.68$, $SD =$

2.45). There were also a significant interaction effects for modality and expertise, $F(1, 168) = 20.27, p < 0.001, \eta_p^2 = .108$, modality and condition, $F(1, 168) = 19.45, p < .001, \eta_p^2 = .104$; and expertise and condition, $F(1, 168) = 138.29, p < .001, \eta_p^2 = .451$. Finally, there was a significant interaction of modality, expertise, and condition, $F(1, 168) = 16.34, p < 0.001, \eta_p^2 = .088$). Pairwise comparisons (with Bonferroni correction) revealed that novices performed better in the audio no-imagery condition compared to the audio imagery condition ($p < .001$), and in the written no-imagery condition compared to the written imagery condition ($p < .001$). However, experts performed better in the audio imagery condition compared to the audio no-imagery condition ($p < .001$) but showed no difference between the written imagery and written no-imagery conditions. Experts also performed better in the audio imagery condition compared to the written imagery condition ($p < .001$) (Please see Figure 3).

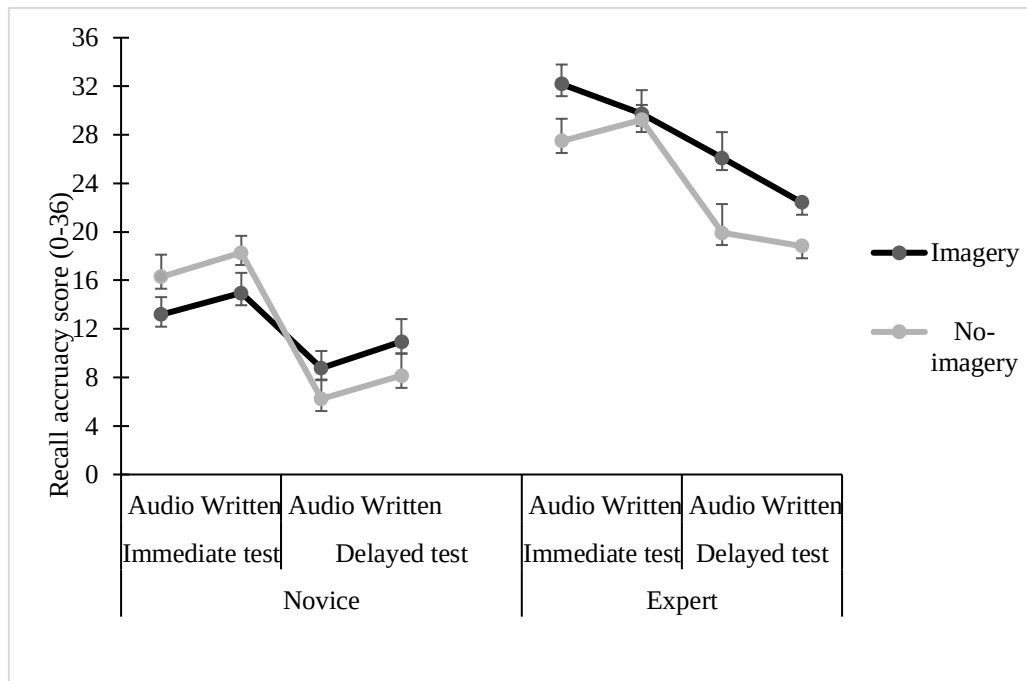


Figure 2. Recall Accuracy Score According to Experimental Condition, Expertise level, and Time of Testing

Hypothesis 3: There will be an interaction between modality, expertise and condition on the delayed recall performance

Table 2. Mean and Standard Deviations for the Learning Outcome Measures as Function of Experimental Conditions and Expertise Level and Time of Testing

	Audio script		Written script	
	Imagery	No-imagery	Imagery	No-imagery
Novice				
Immediate recall (0-36)	13.18 (1.44)	16.31 (1.81)	14.95 (1.67)	18.27 (1.4)
Delayed recall (0-36)	8.77 (1.41)	6.23 (1.60)	10.95 (1.86)	8.14 (1.85)
Expert				
Immediate recall (0-36)	32.18 (1.62)	27.5 (1.64)	29.73 (1.61)	29.23 (1.82)
Delayed recall (0-36)	26.09 (1.95)	19.91 (1.23)	22.41 (2.13)	18.82 (2.38)

Hypothesis 3 was investigated also with three-factorial ANOVAs with modality (audio vs. written), expertise (novice vs expert) and condition (imagery vs. no-imagery) as independent variables, and delayed recall accuracy as dependent variables. The analysis demonstrated no significant main effect of modality, $F(1, 168) = 0.38$, $p = .539$, $\eta_p^2 = .002$, but a main effect of expertise $F(1, 168) = 229.858$, $p < .001$, $\eta_p^2 = .931$, and significant effect of condition, $F(1, 168) = 186.52$, $p < .001$, $\eta_p^2 = .526$. There was also a significant interaction effects for modality and expertise ($F(1, 168) = 63.96$, $p < .001$, $\eta_p^2 = .526$), expertise and condition ($F(1, 168) = 15.83$, $p < .001$, $\eta_p^2 = .086$), and significant interaction effect for modality and condition ($F(1, 168) = 4.37$, $p = 0.038$, $\eta_p^2 = .025$). Finally, there was a significant interaction of modality, expertise, and condition, $F(1, 168) = 6.68$, $p < 0.05$, $\eta_p^2 = .011$. Novices performed better in the audio imagery condition compared to the audio no-imagery condition ($p < .001$, $d = 1.68$), and in the written imagery condition compared to the written no-imagery condition ($p < .001$, $d = 1.51$). Similarly, expert participants performed better in the audio imagery condition compared to the audio no-imagery condition ($p < .001$, $d = 3.79$), and in the

written imagery condition compared to the written no-imagery condition ($p < .001$, $d = 1.59$). Experts also performed better in the audio imagery condition compared to the written imagery condition ($p < .001$, $d = 0.74$), while novice participants performed better in the written imagery condition than the audio imagery condition ($p < 0.001$, $d = 0.95$) (Please see Figure 2).

Discussion

The aim of this study was to investigate how the expertise level (novice vs. expert) and script modality (audio vs. written) impact the effectiveness of two experimental conditions (no-imagery vs. imagery) for learning basketball tactics, and to assess whether these effects persist over time. Regarding cognitive load required for processing the learning materials, the results revealed notable differences between experts and novices in their overall cognitive load investment (Hypothesis 1). Specifically, novice participants perceived the content as more challenging, experienced reduced concentration during learning, and invested greater mental effort when receiving imagery instructions. These findings can be explained by novices heavily relying on the basic external information provided in the study instructions as their primary source of knowledge (Leahy & Sweller, 2004). Consequently, integrating the information presented in the imagery conditions into their existing knowledge structures proved difficult due to their lack of automatized cognitive schemas. As a result, the imagination instructions presented demanding challenges, leading to an increased cognitive load. However, the findings revealed that experts experienced lower cognitive load in the mental imagery condition compared to the no-imagery condition, but only when the content was delivered through the audio version. This indicates that the audio script offers experts a distinct advantage as it allows them to directly and simultaneously imagine the movement or game pattern, resulting in reduced processing demands. The results of this study are in close agreement with previous research on cognitive knowledge or structures in memory (Frank et al., 2014; Frank et al., 2018). The expert players demonstrated a large store of domain-specific knowledge that is

richly interconnected and hierarchically structured. In contrast, the novice participants had a sparse store of knowledge that appeared less hierarchical and disconnected. Essentially, novices exhibited longer processing times for information, as they had a higher cognitive load due to their lower knowledge structures. This was particularly evident when they had to create mental images based on little or no knowledge structures, as opposed to experts who were able to create the image using their pre-existing knowledge structures and schemas (e.g. previous game knowledge and various systems). This ability significantly reduced the cognitive load on working memory.

During immediate testing, an expertise reversal effect emerged (Hypothesis 2), indicating that novices gained a greater advantage in the no-imagery conditions, regardless of the script modality (written or audio). Conversely, experts exhibited a clear benefit from imagery, but specifically when the material was presented through the audio script. This finding aligns with previous research conducted in non-sport learning studies, providing additional support (Cooper et al., 2001; Ginns et al., 2003; Leahy & Sweller, 2004; Lin et al., 2017). One possible explanation for this phenomenon is that inexperienced learners in a specific domain often need to carefully examine and process individual elements of their existing knowledge before they can establish connections and construct new knowledge structures. They must first master the fundamental concepts and techniques before developing more complex knowledge structures. Consequently, novices lacking this fundamental knowledge may not benefit from imagery instructions in the early stages of learning. On the other hand, experienced players derived benefits from the imagery conditions due to their accumulated extensive domain-specific knowledge stored in long-term memory (Didierjean & Marmèche, 2005). This enabled them to actively process the various interconnected information presented in the imagery scripts, resulting in the construction of an effective mental representation of the depicted game system. Furthermore, the imagery effect was shown to be more pronounced when the audio

script was used compared to the written script for expert players. This can be attributed to the audio script's ability to provide experts with a more direct and immersive experience, facilitating the integration of essential information while actively engaging in the process of listening and imagination (Smith & Holmes, 2004). In contrast, the written script may be more difficult to process for experts as it would require them to allocate unnecessary resources for reading and then mentally imagining the presented situation. Such additional demands may impose a cognitive load that hampers immediate recall performances.

Regarding delayed recall, the main findings revealed a different pattern in novice participants' performance, showing a positive effect of the imagery conditions regardless of the script modality (Hypothesis 3). This finding aligns with previous research on the desirable difficulty hypothesis (Bjork, 1994; Bjork & Bjork, 2011), which suggests that learning strategies that require additional cognitive resources may initially impair performance but promote memory and recall in later assessments. In our study, the use of mental imagery conditions facilitated active engagement and a deeper understanding of the material, resulting in knowledge that is more resistant to forgetting and better retained in memory over time (Kühl et al., 2018; Kühl, 2021). Furthermore, the findings revealed that the mental imagery effect is more prominent when using the written script. Unlike the audio script, which presented information at a fixed pace, the written script allowed players to engage in more extensive processing by providing them with additional time to comprehend and integrate the essential information into their long-term memory. In practical terms, with written text, players had the opportunity to adjust their reading speed and revisit complex or ambiguous sections of the text script. While these cognitive tasks may have initially been perceived as challenging for learners, they ultimately encouraged a deeper level of information processing, leading to enhanced immediate recall.

While the present study yielded original findings, it is important to consider its

limitations. Firstly, the study exclusively utilized a single tactical basketball scene as the learning material, which raises questions about the generalizability of the results to materials of varying intrinsic complexities and to other team sports or unrelated domains. Secondly, the study exclusively used verbal representations (text and audio) to convey the learning material, neglecting the inclusion of external visual representations, such as diagrams or videos (Chikha et al., 2022; Ben Chikha et al., 2023a,b; Ben Mahfoudh & Zoudji, 2022; Khacharem et al., 2019). Therefore, further investigation is warranted to explore the impact of combining visual and verbal representations simultaneously on enhancing the effectiveness of imagery. From an applied perspective, the current study highlights the significant influence of player expertise, testing time, and imagery modality on mental imagery. By directly addressing the limitations associated with the masking effect and methodological constraints in real-world motor tasks, the study highlights the effectiveness of our approach in overcoming these challenges. It's noteworthy that novices derive greater benefits from written scripts, which facilitate long-term information retention. Conversely, as players gain expertise in the domain, audio scripts prove to be more effective. Hence, coaches and sports practitioners should carefully consider these factors when aiming to optimize the effective communication of tactical patterns.

DISCUSSION GÉNÉRALE

L'objectif fondamental de cette thèse était d'explorer l'impact de l'imagination sur l'apprentissage de stratégies tactiques en basket-ball, ainsi que sur la charge cognitive associée. Elle visait notamment à déterminer comment l'efficacité de l'imagination varie selon le niveau d'expertise des joueurs et du moment des tests. La discussion générale de cette thèse est structurée en quatre parties distinctes. La première partie offre un aperçu des principaux résultats obtenus dans les différentes études. La seconde partie détaille les apports de la thèse, tant sur le plan théorique que pratique. La troisième partie expose les limitations des études réalisées et propose des directions pour les recherches futures dans ce champ. En conclusion, cette thèse offre une analyse complète et une synthèse des principales découvertes.

Synthèse des Résultats

La méta-analyse présentée dans le **Chapitre 2** avait pour objectif de fournir une compréhension approfondie de l'efficacité de l'imagination sur les résultats d'apprentissage. Bien que Fiorella et Mayer (2015a) aient réalisé une méta-analyse sur l'effet de l'imagination, il est crucial de reconnaître les limites de leur étude et d'explorer les moyens de les surmonter afin d'améliorer la qualité des résultats globaux. Tout d'abord, la méta-analyse de Fiorella et Mayer (2015a) n'a pas suivi les lignes directrices PRISMA en ce qui concerne l'évaluation du risque de biais et de l'hétérogénéité des études incluses. Deuxièmement, le domaine de l'effet de l'imagination est devenu un sujet de recherche distinct et important en psychologie de l'éducation, entraînant de nombreuses études expérimentales. Ces recherches ont identifié plusieurs modérateurs potentiels (comme la complexité du contenu, la modalité matérielle, etc.) qui n'ont pas été pris en compte dans les études précédentes. La présente étude suivra rigoureusement les directives PRISMA, garantissant ainsi la transparence, la répliquabilité et une approche plus rigoureuse de la méta-analyse. En abordant ces limitations et en intégrant les articles les plus récents, cette étude vise à offrir une compréhension plus approfondie de

l'efficacité de l'imagination sur les résultats d'apprentissage. Elle s'est appuyée sur des expériences scientifiquement rigoureuses comparant deux groupes d'élèves : ceux invités à imaginer mentalement les événements décrits dans le matériel d'apprentissage (condition d'imagination) et ceux sans instructions spécifiques (condition de contrôle). Au total, 21 études expérimentales extraites des bases de données PsycINFO, Web of Science, ProQuest Dissertations and Theses, ERIC et Google Scholar ont été analysées, incluant au total 70 comparaisons par paires et 2625 participants. Les résultats ont montré un effet globalement positif sur la rétention et le transfert des connaissances. De plus, l'analyse des facteurs modérateurs a révélé que les tailles d'effet variaient significativement selon les connaissances préalables des apprenants pour les performances de transfert et selon leur niveau d'éducation pour les performances de rétention.

L'étude décrite dans le **Chapitre 3** visait à évaluer l'impact de l'imagination des instructions tactiques verbales de l'entraîneur sur l'amélioration des performances d'apprentissage et la réduction de la charge cognitive. Deux conditions expérimentales ont été mises en œuvre : dans la condition d'imagination, les participants devaient écouter et visualiser les consignes tactiques communiquées oralement ; dans la condition de contrôle, ils devaient simplement écouter ces mêmes instructions. Après l'étude du matériel pédagogique, les joueurs de basketball, tant experts ($N = 40$) que novices ($N = 40$), ont été invités de reconstruire le contenu tactique transmis et indiquer la quantité de charge cognitive associé à la tâche d'apprentissage. Une semaine plus tard, ces mêmes participants ont été invités à effectuer de nouveau cette tâche de reconstruction. Chez les novices, même si l'effet de l'imagination n'était pas observable lors du test immédiat, un impact significatif a été noté lors du test différé. Les résultats indiquent que la condition d'imagerie mentale a stimulé chez les novices un traitement plus actif et profond du contenu appris, les incitant à déployer une charge cognitive substantielle. Bien que cet investissement ait été exigeant initialement, il s'est avéré bénéfique

à long terme, aidant les novices à tirer pleinement avantage de la technique d'imagerie mentale. Pour les experts, l'utilisation de l'imagerie mentale s'est avérée efficace, quel que soit le moment du test. Cette technique semble avoir ciblé de manière efficace les éléments les plus complexes du matériel d'apprentissage, notamment ceux demandant une importante sollicitation de la MdT (Ginns et al., 2003). Cela a favorisé une meilleure intégration de ces éléments dans la MLT et a contribué à l'établissement d'une représentation mentale claire et structurée du système de jeu présenté.

L'étude décrite dans le **Chapitre 4** a exploré comment le timing de l'imagerie mentale affecte l'apprentissage, en particulier si elle devrait être pratiquée simultanément à l'écoute des instructions tactiques ou de manière séquentielle. Cent joueurs de basketball – répartis équitablement entre novices et experts – ont été aléatoirement assignés à l'une des deux conditions : l'imagerie simultanée, où ils devaient écouter et imaginer le contenu en même temps, ou l'imagerie séquentielle, où ils écoutaient d'abord, puis imaginaient le contenu. Pour les novices, l'imagerie simultanée s'est avérée plus efficace. Cette méthode leur a permis de concentrer leur attention immédiatement sur les instructions verbales, facilitant ainsi la formation rapide d'un modèle mental du contenu d'apprentissage présenté par l'entraîneur. Cependant, lorsqu'ils utilisaient l'imagerie séquentielle, ils éprouvaient des difficultés à connecter les informations verbales aux images mentales formées ultérieurement, ce qui pouvait nuire à leur compréhension et à la rétention des informations. Pour les experts, l'imagerie séquentielle était plus bénéfique. Avec leur base de connaissances préexistante et leur expérience, ces joueurs étaient capables de former une représentation mentale précise dès l'écoute initiale des instructions. L'imagerie mentale ultérieure fonctionnait alors comme une révision, leur permettant de vérifier et de peaufiner cette représentation.

L'étude présentée dans le **Chapitre 5** a exploré l'effet de l'association des gestes de traçage avec l'imagerie mentale sur l'apprentissage des mouvements tactiques au basketball.

Les participants, répartis en deux groupes de 46 joueurs novices et 46 joueurs experts, ont été soumis à deux conditions expérimentales : une condition d'imagerie statique (utilisant uniquement l'imagerie mentale) et une condition d'imagerie dynamique (combinant l'imagerie mentale avec des gestes de traçage). Les résultats ont montré que dans les tests de rappel, tant les novices que les experts ont affiché des performances supérieures en condition d'imagerie dynamique comparativement à celle d'imagerie statique. Cette amélioration pourrait s'expliquer par le fait que les gestes de traçage enrichissent l'interprétation et la compréhension des informations spatio-temporelles de jeu (mouvements et interactions complexes) difficiles à simuler mentalement par l'imagerie seule. Ce phénomène est corroboré par la théorie générative de l'apprentissage de Mayer (2009), qui suggère que de telles méthodes améliorent les processus de sélection, d'organisation, et d'intégration de l'information, facilitant ainsi la formation d'une représentation mentale plus complète et efficace du jeu. De plus, des preuves neuroscientifiques (ex. Dodakian et al., 2014 ; Guillot et al., 2013) appuient cette méthode, indiquant que l'intégration de mouvements physiques avec la répétition mentale du mouvement moteur active les régions motrices du cerveau, ce qui peut accroître la clarté et la vivacité du contenu présenté.

L'étude présentée dans le **Chapitre 6** a investigué l'impact de la nature du script d'imagerie mentale (audio ou écrit) sur l'apprentissage de scènes tactiques au basketball chez des joueurs novices (N = 88) et experts (N = 88). Les participants ont été répartis aléatoirement dans quatre conditions expérimentales différentes : (i) Audio-Imagerie : écoute et imagerie mentale des instructions présentées oralement ; (ii) Audio-sans-Imagerie : écoute des instructions sans engagement dans l'imagerie mentale ; (iii) Texte-Imagerie : lecture et imagerie mentale des instructions présentées sous forme écrite ; (iv) Texte-sans-Imagerie : lecture des instructions sans engagement dans l'imagerie mentale. Les novices ont montré de meilleurs résultats avec le script écrit, particulièrement dans le test différé lorsqu'ils s'engageaient dans

l'imagerie mentale. Cette méthode permettait un traitement actif de l'information, offrant aux joueurs la possibilité de contrôler leur rythme de lecture et de revenir sur des sections complexes, ce qui facilitait l'intégration des informations dans leur MLT. Bien que ce processus ait pu sembler exigeant lors du test immédiat des connaissances, il a encouragé un traitement plus profond des informations transmises, aboutissant finalement à de meilleures performances lors du test de rappel différé. Les experts, en revanche, ont principalement bénéficié de la condition audio. Cette modalité offrait une expérience immersive et plus naturelle qui, combinée à leur capacité à traiter efficacement l'information orale, permettait une intégration plus rapide et plus fluide des données dans leur MLT. L'engagement actif dans l'écoute et l'imagination mentale sous forme audio correspondait mieux à leur niveau d'expérience et à leurs compétences préexistantes (Smith & Holmes, 2004). Le script écrit, en revanche, pouvait ralentir ce processus en imposant une charge supplémentaire de lecture avant de pouvoir créer une image de la situation.

Principales contributions de la thèse

Contributions théoriques

Traditionnellement étudiée sous les angles des théories classiques de l'imagerie (ex. théorie bio-informationnelle, Lang, 1979) qui se concentre sur les aspects émotionnels et moteurs liés à la performance. La contribution de la thèse réside dans l'application spécifique de la TCC pour expliquer non seulement l'efficacité de l'imagerie mentale sur les apprentissages tactiques, mais aussi comme un levier pour moduler la charge cognitive (intrinsèque et extrinsèque) y sont associées. Les résultats ont démontré que l'efficacité de l'imagerie mentale n'est pas universelle mais dépend de certains facteurs modérateurs. Un facteur modérateur crucial examiné est l'influence du niveau d'expertise des apprenants sur l'efficacité de l'imagerie mentale. La quantité et la qualité de ces connaissances influencent la manière par laquelle les apprenants sélectionnent, organisent et intègrent les informations dans

leur MLT. Alors que les novices éprouvent des difficultés initiales dans l'utilisation de l'imagerie mentale en raison de l'effort mental important requis, les experts en tirent des bénéfices significatifs. Cette technique semble cibler efficacement les éléments les plus complexes du matériel d'apprentissage, notamment ceux demandant une sollicitation importante de la mémoire de travail (Ginns et al., 2003). Cela contribue à une meilleure intégration de ces éléments dans la MLT et favorise l'établissement d'une représentation mentale claire du système présenté. Cette considération s'aligne sur l'effet de renversement de l'expertise, selon lequel les instructions détaillées peuvent s'avérer redondantes, voire contre-productives pour les experts, en mobilisant des ressources cognitives inutilement (Kalyuga 2007 ; Khacharem et al., 2013b).

Cette thèse a également exploré comment le moment du test influence les résultats de l'apprentissage via l'imagination. En s'appuyant sur l'hypothèse des difficultés désirables (Bjork & Bjork, 2011, 2020), plusieurs études ont démontré que les stratégies qui accroissent l'effort cognitif, bien qu'initialement perturbatrices, favorisent une rétention plus robuste et un rappel plus efficace à long terme. Cette approche consolide la trace mnésique de l'information en la rendant moins sujette à l'oubli. Nos travaux sur l'efficacité de l'imagerie mentale confirment cette hypothèse : initialement, l'utilisation de l'imagerie mentale représente un défi cognitif important. Lorsque les apprenants sont invités à imaginer mentalement des instructions tactiques ou des concepts de manière détaillée, cela requiert un effort cognitif considérable pour générer, maintenir et manipuler ces représentations mentales (Cumming & Eaves, 2018). Ce processus engage intensivement la MdT, nécessitant une coordination simultanée de multiples types d'informations, ce qui est initialement exigeant en termes de ressources cognitives. Toutefois, ces défis initiaux, loin d'être des obstacles, sont des activités cognitives cruciales qui facilitent la construction et l'automatisation des schémas en MLT (Sweller, 2020 ; Sweller et al., 2019). Ainsi, l'imagerie mentale se révèle être une stratégie extrêmement

bénéfique pour un apprentissage durable. À l'opposé, des informations acquises trop facilement, sans l'engagement dans des activités génératives (i.e., l'imagerie mentale), tendent à laisser une empreinte moins marquée dans la mémoire, rendant leur récupération plus difficile après un certain délai.

Contributions Pratiques

Cette thèse met en lumière des contributions pratiques importantes pour les entraîneurs de basketball qui cherchent à améliorer l'acquisition et l'apprentissage des tactiques sportives chez leurs joueurs. En intégrant des sessions d'imagerie mentale avant les entraînements ou les matchs, les entraîneurs peuvent aider les athlètes à mieux assimiler des stratégies tactiques, surtout lorsque celles-ci sont difficiles à expliquer verbalement. Cette technique aide les joueurs à saisir précisément leur rôle et leur positionnement par rapport aux coéquipiers et adversaires, ce qui améliore l'exécution des plans de jeu. Il est important de noter que pour les novices, une écoute attentive des instructions verbales peut être un bon point de départ pour obtenir de bonnes performances à court terme. Cependant, pour développer des stratégies et des comportements collectifs durables, l'imagerie mentale est cruciale pour une intégration plus profonde des systèmes de jeu.

En plus de l'imagerie mentale classique, *l'ajout de gestes physiques* durant ces sessions s'est révélé augmenter significativement la rétention des actions tactiques. Les entraîneurs peuvent encourager les joueurs à simuler des mouvements avec leurs mains pendant l'imagerie pour mieux ancrer les instructions et renforcer l'apprentissage des séquences de jeu. La *personnalisation des sessions d'imagerie mentale* est également essentielle pour maximiser leur efficacité. Les résultats de la thèse encouragent les entraîneurs à adapter les scripts d'imagerie mentale en fonction du niveau d'expertise des joueurs. Pour les novices, souvent moins habitués à imaginer mentalement des stratégies complexes, les scripts écrits sont particulièrement avantageux. Ils offrent une structure claire et une référence tangible que les

joueurs peuvent suivre à leur propre rythme, facilitant ainsi la compréhension et la mémorisation des mouvements et des positions tactiques. Il est également conseillé d'employer l'imagerie simultanée pour ces débutants, une méthode où ils écoutent le script tout en imaginant le contenu en même temps. À l'inverse, les joueurs plus expérimentés, disposant d'une base de connaissances tactiques plus développée, bénéficient davantage des scripts oraux surtout lorsqu'ils sont présentés avant la session d'imagerie mentale. Cette approche facilite une immersion plus dynamique et interactive, ce qui est essentiel pour la construction d'une représentation mentale précise et détaillée de la stratégie tactique décrite par l'entraîneur.

En résumé, ces résultats montrent que l'imagerie mentale, surtout lorsqu'elle est adaptée aux ressources du joueur et/ou combinée avec des gestes physiques, joue un rôle significatif dans l'enseignement des tactiques sportives. Bien que ces résultats aient été spécifiquement appliqués au basketball, leur pertinence peut s'étendre à d'autres sports d'équipe qui partagent les mêmes défis en matière de formation et d'exécution de stratégies complexes.

Limites et Perspectives

Les résultats de cette recherche apportent des contributions significatives à la fois pour la communauté scientifique et pour les praticiens. Cependant, il est important de noter également que les études réalisées comportent des limites qui nécessitent des investigations supplémentaires. Cette thèse a mobilisé la TCC (Sweller, 1988 ; Sweller et al., 2020) pour analyser les mécanismes cognitifs sollicités lors de l'apprentissage par l'imagination. Toutefois, cette théorie psychologique présente des restrictions, notamment dans la capacité à déterminer précisément quelles zones du cerveau sont activées, l'intensité de cette activation et sa durée. Pour pallier ces insuffisances, il est indispensable d'employer des méthodes d'investigation objectives comme l'électroencéphalographie (EEG) et l'imagerie par résonance magnétique fonctionnelle (IRMf) (Guillot et al., 2009 ; Guillot et al., 2014). L'EEG est particulièrement utile pour fournir des mesures en temps réel de l'activité électrique du cerveau, qui permet

d'observer les fluctuations dynamiques des ondes cérébrales lors de l'imagerie mentale (Cremade et al., 2010 ; Wilson et al., 2016). D'autre part, l'IRMf offre une résolution spatiale de haute précision, essentielle pour localiser avec exactitude les régions du cerveau impliquées et pour mesurer l'intensité de leur activation (Harrison et al., 2017). Bien que ces techniques aient déjà été utilisées pour examiner les effets de la pratique mentale sur l'acquisition de compétences motrices (Guillot et al., 2009 ; Guillot et al., 2014), leur utilisation pour l'étude de l'apprentissage des stratégies et tactiques dans les sports d'équipe reste inexplorée et mérite d'être étudiée dans des recherches futures.

Deuxièmement, les conclusions de cette thèse ne permettent pas d'explorer en détail l'impact de l'imagerie mentale sur les performances tactiques réelles sur le terrain. Le paradigme de rappel-reconstruction adopté a demandé aux joueurs de dessiner, individuellement, des situations de jeu sur papier. Cette approche a certes permis d'éliminer l'effet de masquage, souvent observé lors des interventions de groupe, qui tend à occulter les variations individuelles (Munroe-Chandler et al., 2005 ; Bryan, 1987; Shambrook & Bull, 1996). Toutefois, elle ne reflète pas fidèlement les conditions dynamiques et complexes d'un véritable match de basketball, où les joueurs doivent prendre des décisions rapides et mettre en œuvre leurs stratégies sous une pression physique et psychologique immédiate. La reconstruction sur papier, bien qu'utile pour analyser certains aspects cognitifs dans un cadre strictement contrôlé, ne capture pas l'urgence (Macquet, 2009) ni les interactions physiques caractéristiques des rencontres réelles, ce qui peut par conséquent limiter la portée et la généralisabilité des résultats. Pour mieux comprendre l'efficacité de l'imagerie mentale dans l'amélioration des performances sportives, il serait donc bénéfique de développer des méthodes d'expérimentation qui miment plus étroitement les situations de jeu réelles et qui permettent d'évaluer directement sur le terrain les compétences tactiques acquises.

Les capacités d'imagerie mentale, qui varient de faibles à élevées, jouent un rôle

crucial. Un joueur doté de fortes capacité d'imagerie mentale pourrait bénéficier particulièrement d'un programme d'imagerie mentale, améliorant ainsi sa capacité à assimiler des instructions complexes. De même, les joueurs avec des capacités d'imagerie mentale moindres pourraient tirer un avantage particulier de l'exécution de gestes de traçage pendant le processus d'imagerie mentale (étude 3). En outre, la préférence en matière d'imagerie, qu'elle soit en première personne (comme si l'athlète participait activement à l'exécution de la tactique, favorisant ainsi un sentiment d'immersion plus profond) ou en troisième personne (se voyant comme un observateur externe qui permettrait de bénéficier d'une vue plus globale des informations de jeu), influence l'assimilation et l'application des instructions tactiques. Ainsi, adapter les scripts d'imagerie en fonction de ces préférences pourrait améliorer la capacité de chacun à assimiler les informations tactiques. Il est également important de noter que les études discutées ont été exclusivement menées auprès d'adultes masculins (principalement en raison des difficultés à engager des équipes féminines et des centres de formation de la région). Cette limitation souligne l'importance de considérer que les résultats pourraient ne pas être généralisables aux femmes ou à d'autres tranches d'âge (les enfants ou les adolescents). L'ensemble de ces observations mettent en évidence le besoin d'études complémentaires pour valider l'universalité de ces résultats et enrichir notre compréhension des impacts de l'imagerie mentale sur l'apprentissage des stratégies tactiques.

Conclusion

Les résultats de cette thèse ont mis en évidence deux points fondamentaux : D'une part, les recherches présentées – la méta-analyse ainsi que les études expérimentales – ont révélé un impact positif global de l'utilisation de l'imagerie mentale sur l'apprentissage, en comparaison avec les méthodes traditionnelles. D'autre part, elles ont identifié des facteurs modérateurs – tels que le niveau d'expertise des joueurs et le moment des tests – qui peuvent influencer cet effet. Il est donc essentiel pour les entraîneurs d'ajuster leurs stratégies pédagogiques en tenant compte de ces variables pour optimiser la transmission et l'assimilation des stratégies tactiques dans le contexte du basketball. Ce travail de thèse enrichit significativement la littérature en psychologie du sport en introduisant de nouvelles perspectives sur l'utilisation de l'imagerie mentale dans la formation et l'apprentissage des tactiques sportives. En mettant en évidence ces aspects, cette thèse plaide en faveur d'une révision des méthodes d'entraînement traditionnelles et encourage une adoption plus systématique de l'imagerie mentale pour favoriser le développement des compétences tactiques chez les sportifs.

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ANNEXES

Questionnaire sur la Vivacité de l'Imagerie Visuelle

VIVIDNESS OF VISUAL IMAGERY QUESTIONNAIRE

(VVIQ - Marks, 1973)

Traduction en français en version électronique

Santarpia, A., Poinso R. (2007)

Equipe de Recherche en Psychologie clinique, Université Paris 8

Nom :

Age : ans

Sexe :

Date : / /

Profession :

TOTAL DES SCORES :
YEUX OUVERTS (YO) :
YEUX FERMES (YF) :
Total (YO + YF) =

Introduction

Grâce au tableau ci-dessous, vous allez explorer le niveau de vivacité de l'image mentale évoquée par chaque proposition au moyen d'une échelle en 5 points. Vous allez explorer les images mentales obtenues selon deux modalités : yeux ouverts (YO) et yeux fermés (YF). Exécutez bien toutes les propositions. Essayez de faire chaque item du questionnaire sans être influencé par l'item précédent.

L'image mentale évoquée par une proposition peut correspondre à :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement nette et vivace.	3
L'image est relativement nette, presque aussi précise et vivace qu'une perception.	4
L'image est parfaitement nette, aussi précise et vivace qu'une véritable perception.	5

ITEMS 1-4 (YO) : Imaginez attentivement un(e) ami(e) que vous voyez fréquemment (qui n'est pas présent(e) en ce moment) :

1. Le contour exact de son visage, de sa tête, de ses épaules et de son corps :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

2. Les positions de sa tête, les postures de son

corps, etc. : Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

3. Sa démarche précise, la longueur de ses pas, etc. lorsqu'il (elle)

marche : Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

4. Les différentes couleurs de certains de ses vêtements habituels :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

ITEMS 5-8 (YO) : Imaginez le lever du soleil. Analysez attentivement l'image qui apparaît :

5. Le soleil se lève à l'horizon dans un ciel brumeux :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

6. Le ciel s'éclaircit et entoure le soleil de bleu :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

7. Nuages. Une tempête éclate avec des éclairs :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

8. Un arc-en-ciel apparaît :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

ITEMS 9–12 (YO) : Imaginez un magasin dans lequel vous allez souvent. Analysez en détail l'image qui vous vient à l'esprit :

9. La devanture du magasin qui se trouve de l'autre côté de la rue :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

10. Une vitrine avec les couleurs, la forme et les détails des articles en vente :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

11. Vous êtes proche de l'entrée. La couleur, la forme et les détails de la porte :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

12. Vous entrez dans le magasin et vous allez vers la caisse. Le commerçant vous sert. Vous lui donnez l'argent qu'il prend :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

ITEMS 13–16 (YO) : Imaginez une scène de campagne avec des arbres, des montagnes, un lac. Analysez, en détail, les images que vous visualisez en esprit :

13. Les contours du paysage :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

14. La couleur et la forme des arbres :	
Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5
15. La couleur et la forme du lac :	
Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5
16. Un vent fort s'abat sur les arbres et sur le lac en produisant des vagues :	
Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

SCORE TOTAL YO : YEUX OUVERTS (YO) :
--

ITEMS 1-4 (YF) : *Imaginez attentivement l'image d'un(e) ami(e) que vous voyez fréquemment (qui n'est pas présent(e) en ce moment) :*

1. Le contour exact de son visage, de sa tête, de ses épaules et de son corps :	
Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5
2. Les positions de sa tête, les postures de son corps, etc. :	
Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5
3. Sa démarche précise, la longueur de ses pas, etc. lorsqu'il (elle) marche :	
Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5
4. Les différentes couleurs de certains de ses vêtements habituels :	
Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

ITEMS 5–8 (YF) : Imaginez le lever du soleil. Analysez attentivement l'image qui apparaît :

5. Le soleil se lève à l'horizon dans un ciel brumeux :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

6. Le ciel s'éclaircit et entoure le soleil de bleu :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

7. Nuages. Une tempête éclate avec des éclairs :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

8. Un arc-en-ciel apparaît :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

ITEMS 9–12 (YF) : Imaginez un magasin dans lequel vous allez souvent. Analysez en détail l'image qui vous vient à l'esprit :

9. La devanture du magasin qui se trouve de l'autre côté de la rue :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

10. Une vitrine avec les couleurs, la forme et les détails des articles en vente :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

11. Vous êtes proche de l'entrée. La couleur, la forme et les détails de la porte :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

12. Vous entrez dans le magasin et vous allez vers la caisse. Le commerçant vous sert. Vous lui donnez l'argent qu'il prend :

Aucune image n'est visible.	1
L'image est vague et imprécise.	2
L'image est moyennement claire et nette.	3
L'image est relativement claire, presque aussi nette et précise qu'une perception.	4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.	5

ITEMS 13–16 (YF) : *Imaginez une scène de campagne avec des arbres, des montagnes, un lac.*

Analysez, en détail, les images que vous visualisez en esprit :

13. Les contours du paysage : Aucune image n'est visible.		1
L'image est vague et imprécise.		2
L'image est moyennement claire et nette.		3
L'image est relativement claire, presque aussi nette et précise qu'une perception.		4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.		5
14. La couleur et la forme des arbres : Aucune image n'est visible.		1
L'image est vague et imprécise.		2
L'image est moyennement claire et nette.		3
L'image est relativement claire, presque aussi nette et précise qu'une perception.		4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.		5
15. La couleur et la forme du lac : Aucune image n'est visible.		1
L'image est vague et imprécise.		2
L'image est moyennement claire et nette.		3
L'image est relativement claire, presque aussi nette et précise qu'une perception.		4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.		5
16. Un vent fort s'abat sur les arbres et sur le lac en produisant des vagues : Aucune image n'est visible.		1
L'image est vague et imprécise.		2
L'image est moyennement claire et nette.		3
L'image est relativement claire, presque aussi nette et précise qu'une perception.		4
L'image est parfaitement claire, aussi nette et précise qu'une véritable perception.		5

SCORE TOTAL YF :

YEUX FERMES (YF) :

Matériel d'apprentissage

Introduction

Bonjour, aujourd'hui nous allons apprendre un système de jeu appelé (SHORT) pour attaquer une défense homme à homme. Ce système est composé de 4 étapes successives, qui commence par le dribble du joueur #1 et fini par le tir de ce même joueur.

Etape 1 :

L'action se débute lorsque le meneur de jeu #1 situé à l'extrémité gauche de la tête de la raquette effectue rapidement des dribbles de décalage vers la droite. Il s'arrête à l'extrémité droite de la tête de la raquette. En même temps, L'ailier #3, situé à 3 points à 0° à gauche, prend les deux écrans successifs diagonaux vers le haut de la part de l'ailier fort #4 (situé au poste bas à gauche) et le pivot #5 (situé au poste haut à gauche). Il se déplace ensuite vers le poste bas à droite afin de décaler la défense et préparer à la mise en place de l'action suivante. L'arrière #2 se positionne à 3 points à 0° à droite.

Etape 2 :

Le pivot #5 situé au niveau du prolongement imaginaire de la ligne des lancers francs à gauche, vient porter un écran à l'ailier fort #4 situé à mi-distance à 0° à gauche. L'ailier fort #4 prend l'écran et vient se placer à 3 points à 45° à gauche. Le meneur de jeu #1 situé à l'extrémité droite de la tête de la raquette passe le ballon à l'ailier fort #4 pour tenter de faire un tir de 3 points. En même temps, l'arrière #2 situé à 3 points à 0° à droite remonte vers l'angle 45° du

même côté pour assurer le repli défensif avec le meneur #1. L'ailier #3 garde sa position au poste bas à droite.

Etape 3 :

Le pivot #5 situé à mi-distance 0° à gauche, fait un écran latéral à l'ailier #3 afin de réceptionner la balle sous le panier pour marque 1 contre 0. L'ailier #3 situé au poste bas à droite prend l'écran et vient se placer au poste bas à gauche. Après son écran, le pivot #5 s'ouvre vers le milieu de la raquette pour demander la balle de l'ailier fort #4 situé à la ligne de 3 points à l'angle 45° à gauche.

En même temps, le meneur de jeu #1 situé à l'extrémité droite de la tête de la raquette vient se repositionner en tête de la raquette pour assurer un meilleur espace de jeu entre lui, l'ailier fort #4 et l'arrière #2. L'arrière #2 garde sa position à trois points à 45° à droite.

Etape 4 :

En arrivant à la fin des actions, la préparation au tir commence lorsque l'ailier fort #4 situé à la ligne de 3 points à l'angle 45° à gauche fait une passe au meneur de jeu #1 qui se situe en tête de la raquette. En même temps, le pivot #5 situé au milieu de la raquette vient vite porter un écran au meneur de jeu #1.

Le meneur de jeu #1 prend l'écran et dribble vers le panier pour achever l'action par un tir à l'arrêt ou un double pas. L'arrière #2 garde sa position à 3 points à 45° à droite et l'ailier #3 garde sa position au poste bas à gauche.

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Résumé

Titre : Apprentissage de Scènes Tactiques par Imagination : Impacts de l'Expertise et du Moment du Test

L'effet de l'imagination se manifeste lorsque les individus qui imaginent mentalement un événement obtiennent de meilleurs résultats à un test ultérieur par rapport à ceux qui ont étudié cet événement de manière conventionnelle. Reconnue comme une stratégie d'apprentissage générative, l'imagination a été largement exploitée dans le domaine académique pour améliorer la compréhension et l'apprentissage. Toutefois, son potentiel dans le développement de compétences sportives, notamment tactiques, reste peu exploré. Cette thèse vise à analyser cet aspect en évaluant spécifiquement l'efficacité de l'imagination selon le niveau d'expertise des joueurs et le moment de réalisation des tests. Les résultats indiquent que les experts tirent un bénéfice significatif de l'imagination, aussi bien dans les tests immédiats que dans ceux administrés après un délai. Pour les novices, l'imagination semble initialement impacter négativement les performances immédiates, en comparaison avec des stratégies d'apprentissage plus passives (la simple écoute ou la lecture des instructions tactiques). Cependant, ce phénomène s'inverse sur le long terme, où l'imagination s'avère finalement bénéfique. La thèse révèle également que l'efficacité de l'imagination est modulée par plusieurs facteurs, dont la nature de l'imagerie (statique versus dynamique), le format de présentation du script d'imagerie (écrit versus oral), et le moment de la présentation du script (pendant versus après l'acte d'imaginer). Les résultats de la thèse sont discutés autour de la théorie de la charge cognitive et mobilisent des concepts tels que l'effet de renversement de l'expertise et l'hypothèse des difficultés désirables.

Mots clés : Imagination, Apprentissage, Tactique, Expertise, Difficultés désirables, Charge cognitive, Basketball

Abstract

Title: Learning Tactical Scenes by Imagination: Impacts of Expertise and Time of Testing

The effect of imagination manifests when individuals mentally imagine an event, showing better results in a subsequent test compared to those who studied the event conventionally. Recognized as a generative learning strategy, imagination has been widely utilized in academic field to enhance understanding and learning. However, its potential in the development of sports skills, particularly tactical ones, remains underexplored. This thesis aims to analyze this aspect by specifically assessing the effectiveness of imagination based on players' expertise levels and the timing of test administration. The results indicate that experts derive significant benefits from imagination, both in immediate tests and those administered after a delay. For novices, imagination initially appears to negatively impact immediate performance compared to more passive learning strategies (such as simple listening or reading of tactical instructions). However, this phenomenon reverses in the long term, where imagination ultimately proves beneficial. The thesis also reveals that the effectiveness of imagination is modulated by several factors, including the nature of imagery (static versus dynamic), the format of imagery script presentation (written versus oral), and the timing of script presentation (during versus after the imagining act). The thesis results are discussed in light of cognitive load theory and incorporate concepts such as the expertise reversal effect and the desirable difficulties hypothesis.

Key words: Imagination, Learning, Tactical, Expertise, Desirable difficulties, Cognitive load, Basketball